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AN ASSESSMENT OF SUBMARINE APPROACH OFFICER DECISION-MAKING AND ITS IMPLICATIONS FOR COMMAND WORKSTATION DESIGN

By

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U.S. Navy Submarine Approach Officers (AO) use tactical skills acquired from years at sea and a seemingly natural panache to accurately determine an enemy submarine's bearing, range, course, and speed. This thesis investigates the effects of AO demographic differences and combat system employment methodologies on the ability to develop a timely and accurate firing solution. Employing a low-resolution submarine combat simulator, approximately 10 percent of the total pool of AO's were taken through two of four pre-scripted initial contact scenarios. The AO's were instructed to execute each scenario until they perceive that an accurate solution is obtained on the enemy submarine. The demographic differences of geographic location, ship type, and duty type are the top three traits that distinguish between success and failure. Further data analysis reveals differences in the information utilization of the simulator between successful and unsuccessful operators. Additionally, utilizing a survey administered to the subjects and basic display design principles, a notional command workstation for the next generation of submarine is developed. The conclusions of this research provide insight into the cognitive modeling, training, and selection of AO's, as well as adding to the growing body of work in the design of military decision support systems.

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AN ASSESSMENT OF SUBMARINE APPROACH OFFICER DECISION-MAKING AND ITS IMPLICATIONS FOR COMMAND WORKSTATION DESIGN

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ABSTRACT

U.S. Navy Submarine Approach Officers (AO) use tactical skills acquired from years at sea and a seemingly natural panache to accurately determine an enemy submarine's bearing, range, course, and speed. This thesis investigates the effects of AO demographic differences and combat system employment methodologies on the ability to develop a timely and accurate firing solution. Employing a low-resolution submarine combat simulator, approximately 10 percent of the total pool of AO's were taken through two of four pre-scripted initial contact scenarios. The AO's were instructed to execute each scenario until they perceive that an accurate solution is obtained on the enemy submarine. The demographic differences of geographic location, ship type, and duty type are the top three traits that distinguish between success and failure. Further data analysis reveals differences in the information utilization of the simulator between successful and unsuccessful operators. Additionally, utilizing a survey administered to the subjects and basic display design principles, a notional command workstation for the next generation of submarine is developed. The conclusions of this research provide insight into the cognitive modeling, training, and selection of AO's, as well as adding to the growing body of work in the design of military decision support systems.

DISCLAIMER

The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

The reader is cautioned that the computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logical errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

The simulator utilized in this research was developed by the Naval UnderSea Warfare Center (NUWC). Any inquires concerning its origination or use should be directed to NUWC.

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EXECUTIVE SUMMARY

Recent changes in U.S. Naval doctrine have underscored the need for Navy ships to operate in the littoral regions of the world. Operating in proximity to congested coastal regions present unique challenges to the military decision-maker. Frequently, there is no clear-cut answer about a specific situation or decision. Rapidly unfolding events result in severe time pressure and extreme, often fatal, consequences. Current real-time battle-space management systems are well suited to the demands of a protracted blue water conflict. However, their ability to be optimally employed in the emergent fast-moving littoral environment is questionable.

Project NEMO (Naval Expertise and MOdeling) was initiated by the Naval UnderSea Warfare Center (NUWC) to explore Combat Control System (CCS) modifications to best meet Submarine Approach Officers (AO) needs in these new environments. Project NEMO's ultimate goal is "to provide for the layout, design, and implementation of a Submarine Command Workstation (CWS) to be incorporated into the New Attack Submarine (NSSN)". Utilizing a small cadre of submarine officers stationed at NUWC, Project NEMO researchers are currently in the process of modeling the AO's cognitive processes during tactical engagements. While the initial CCS for the NSSN is in the final stages of development, it is postulated that lessons learned from Project NEMO will influence future upgrades and provide for system improvements.

This thesis has three primary objectives. The first objective is to explore possible relationships between both subject demographic differences and CCS employment strategies in the prediction of a successful engagement. The second objective is to provide data in the development of a notional "AO friendly" CWS interface. It is

postulated that this interface will allow the AO to more accurately evaluate relevant tactical information with less effort through the use of more appropriate information presentation and display formatting. The third objective is to provide for principles which could be applied in the areas of personnel selection, qualification, and training.

A low-resolution computer-based CCS simulation was used to run subjects though two of four pre-scripted initial contact scenarios in a modified Latin square design. The subject pool comprised approximately 10% of the active duty U.S. AO's. The study used two objective measures of effectiveness, solution accuracy at time of fire (TOF) and weapon to target closest point of approach (CPA), and one subjective measure of effectiveness; the determination of a "successful" engagement. In addition, subjects participated in a design survey to provide feedback on not only the simulation, but also their desires for the next generation CWS.

An exploratory statistical analysis was performed on the subject-generated database with the goal of determining if demographic distinctions and CCS usage strategies among AO's could be used to predict the quality of a simulated engagement. Regression techniques were then applied to the MOE's obtained for the subjects. Geographical location, ship type, and duty type were the three most important determinants in the prediction of a successful engagement. Surprisingly, no distinction between experts and novice operators was found with the MOE's. Coupling this finding with an almost zero correlation between accuracy and number of years at sea, a hallmark for expert designation, raises the question as to whether a good AO is "born or made". Analysis of the linear relationships between TOF and CPA revealed two important observations: 1) the shorter the engagement, the more accurate target solution, and 2)

expert vs. novice distinction is negligible, while geographical location, ship type, and education are significant factors in predicting success.

A single step link analysis was examined on both display usage and solution generation. Rather than examining the differences between expert and novice AO's, the differences between successful and unsuccessful AO's were used instead. It was shown that successful and unsuccessful subjects do in fact demonstrate variance in the cognitive progression of links in both display usage and solution generation. The successful subjects were shown to follow standard submarine liturgy and submerged approach methodology while unsuccessful subjects were observed to be acting in an ad hoc manner (i.e. "easter egging"). This further reinforces the benefit of reliance on established methodologies and techniques and provides for applications in the periodic reevaluation and training of AO's.

Results from the two link analyses were contrasted with both subject evaluations of the current CCS's and subject desires for CCS attributes into a preliminary CWS design. While originally it was envisioned subjects would only "brainstorm" the CWS fire control module, subject dissatisfaction with current CCS's and the desire for a revolutionary leap in its employment, significantly expanded the scope of subject inputs. The final product can be viewed as a notional design concept for a complete CWS.

The main value of this study is the continued exploration of the cognitive processes of the submarine AO. The results obtained have implications in initial selection, periodic reevaluation, career progression, and training regimen of personnel. The data collected in the course of this research will continue to provide additional insight and future work should continue to explore the hypothesis not yet examined.

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DEDICATION

I dedicate this thesis to my wife Jennifer and our new son William. It is from them that I draw my strength and serenity.

I. INTRODUCTION

Changes in United States strategic priorities have generated an increased need for U.S. Navy ships to operate in the littoral regions of the world (Department of the Navy, 1996). Naval doctrine specifies that the near term battle-space will be exclusively in the littorals. Littoral regions, defined as the area within 200 nautical miles of the coastline, necessitate operations in the congested, confined water and airspace close to an adversary's shores (Hutchins, 1995). Littoral warfare presents unique challenges to the decision-maker for it entails multi-faceted scenarios characterized by rapidly unfolding events involving contact identification, comprehension of intent, consideration of available responses, and forecasting potential consequences. Frequently, there are no clear-cut answers about specific situations and often these events can have extreme, even fatal, consequences for errors (Collyer & Malecki, 1998). Current real-time battle-space management systems are well suited to the demands of protracted blue water conflicts; however, their viability in the littoral environment is questionable.

A. BACKGROUND

There have been several well-publicized and unfortunate events that have focused the military's attention on the difficult decisions facing U.S. Naval commanders in the littorals. The 1987 USS STARK (Levinson, 1997) and the 1988 USS VINCENNES (Rogers, 1996) incidents are still fresh in the Navy's collective consciousness. In the case of the STARK, a harassing Iraqi F-4 jet was allowed to shoot two anti-ship missiles, severely damaging the ship and tragically resulting in 37 crew fatalities. This situation was predicated by the confusing and contradictory rules of engagement (ROE) under which the STARK was operating. In the case of the VINCENNES, an Iranian

commercial jetliner carrying 288 civilians was mistakenly identified as an inbound hostile aircraft, and was consequently shot down. The official after action report on the VINCENNES incident found that the decision making process was influenced by the events surrounding the STARK the year before. While circumstances leading up to, and surrounding the two events are very different, in both cases the basic mistake remains the same. The Commanding Officer (CO), operating under conditions of extreme stress, made the wrong decision about whether or not to engage an inbound aircraft.

In recognition of the complex and difficult decisions that led up to the STARK and VINCENNES incidents, the Tactical Decision-Making Under Stress (TADMUS) program was initiated (See Appendix A for a full discussion of TADMUS). The objective of the TADMUS program was to explore the areas of human factors and training technology in order to develop and apply principles that could help avoid such incidents in the future (Bowers & Salas, 1998). TADMUS strives to act as an intelligent assistant to the CO/Tactical Action Officer (TAO) team of an AEGIS cruiser during periods when the mental workload exceeds the teams combined cognitive capacity. It enhances the visual stimulus presented to the team while simultaneously overcoming their cognitive limitations in support of a recognition primed heuristic for the current tactical scenario. Furthermore, it attempts to model the human cognitive decision making process by independently forming hypotheses concerning target motivation and subsequent own ship response options. At the time of this research, TADMUS was in the process of undergoing final approval prior to implementation aboard AEGIS cruisers (Morrison, Kelly, Moore, & Hutchins, 1998).

There are several “submerged events" similar to the STARK and VINCENNES incidents that currently weigh heavily on the U.S. Navy Submarine community. The classification of this paper does not permit a frank discussion of such incidents, but it suffices to say that such incidents do occur (Bowermaster, 1993; Clancy, 1997). In fact, only recently has the 1993 underwater collision between the USS GRAYLING and a Soviet Delta class SSBN in the North Sea been made public. The Submarine community has realized the potential benefits of a TADMUS-like system and is eagerly pursuing the acquisition of such a system.

The Naval UnderSea Warfare Center (NUWC) initiated Project NEMO (Naval Expertise and MOdeling) in the mid-1990's to examine possible changes for the current Combat Control System (CCS) that best meet the needs of the Submarine Approach Officers (AO) during a tactical engagement. Project NEMO’s ultimate goal is “to provide for the layout, design, and implementation of a Submarine Command Workstation (CWS) to be incorporated into the New Attack Submarine (NSSN)” (Kirschenbaum, 1997). Project NEMO researchers are currently modeling the AO's cognitive processes during tactical engagements based on a small a small cadre of Submarine officers stationed at NUWC (Kirschenbaum, 1997). However, the program is still in the infancy stage, with many years of difficult work ahead. While the initial CCS for the NSSN is currently in its final stages of development, it is hoped that Project NEMO's findings will influence future upgrades and provide for substantial improvements.

B. OBJECTIVE STATEMENT

By understanding and capitalizing upon the AO's cognitive processes, the CWS could allow for a more accurate evaluation of relevant tactical information with less effort as compared to existing tactical displays. Thus, this thesis has two primary objectives:

1) To assess the relationship between both AO demographic variables, such as rank, experience, education, etc., and AO CCS employment strategies to the probability of a "successful" tactical engagement. These variables and strategies could then be used as weighting factors in the areas of personnel selection and qualification.

2) To develop a basic design concept for an "AO friendly" CWS interface based on the CCS informational usage, display employment frequency, and AO subjective inputs. This interface would be the centerpiece for an AO decision support system. This system could also be used as a training aid during mission preparation.

C. STATEMENT OF THE PROBLEM

Cognitive task analysis of the AO and their goal allocation structure has been examined in detail as an initial part of Project NEMO (Kirschenbaum, 1997). The next stage focuses on what accounts for the differences between "successful" and "unsuccessful" AO's. Specifically, the questions to be answered are: are the mental models of AO's, as they relate to informational usage from the CCS, the same and do successful and unsuccessful AO's share the same level of situational awareness throughout the course of a tactical scenario? It is thought that the AO's CCS usage

strategy and success rate might be related to their status as either an "Expert" or "Novice" AO. Demographic variables such as current job, ship type, location stationed, general computer experience, combat system experience, and post-secondary education might be also be factors that contribute in the distinction between CCS usage strategies and the prediction of success.

Currently, AO's have no display specifically designed to give them the "big picture" of an engagement. Figure 1.1 shows the typical tactical aid that submarine AO's use to plan and execute attacks. The tactical aid is actually an 8-inch square piece of plexi-glass covering a standard naval maneuvering board. The writing on the tactical aid comes from a black grease pencil used by the AO. Information such as own-ship's current and past course, speed, and depth, current sub-surface and surface environmental conditions, ancillary contact parameters, as well as pertinent contact kinematics are typically detailed on the tactical aid. It should be noted though, that there is neither a defined set of requirements for what information that should be placed on the tactical aid nor a prescribed format for that information. It is simply a matter of personal choice. Additionally, in order to construct this tactical aid, the AO compiles information from up to fourteen distinct displays, five individuals, and three separate locations within the submarine control area. Once gathered, the data is manually correlated for each target in the current situation, and then all targets are correlated to achieve the big picture. Compounding this situation, the submarine control area typically has 30-45 men in a very confined space of as little as 25 x 25 feet. Such environmental distracters only serve to degrade a commander's already reduced capability to successfully execute his primary task. This is an unacceptable situation, and therefore an attempt will be made to develop

a notional submarine command level display concept that provides for more complete utilization of information and an increased situational awareness (Kirschenbaum, 1997).

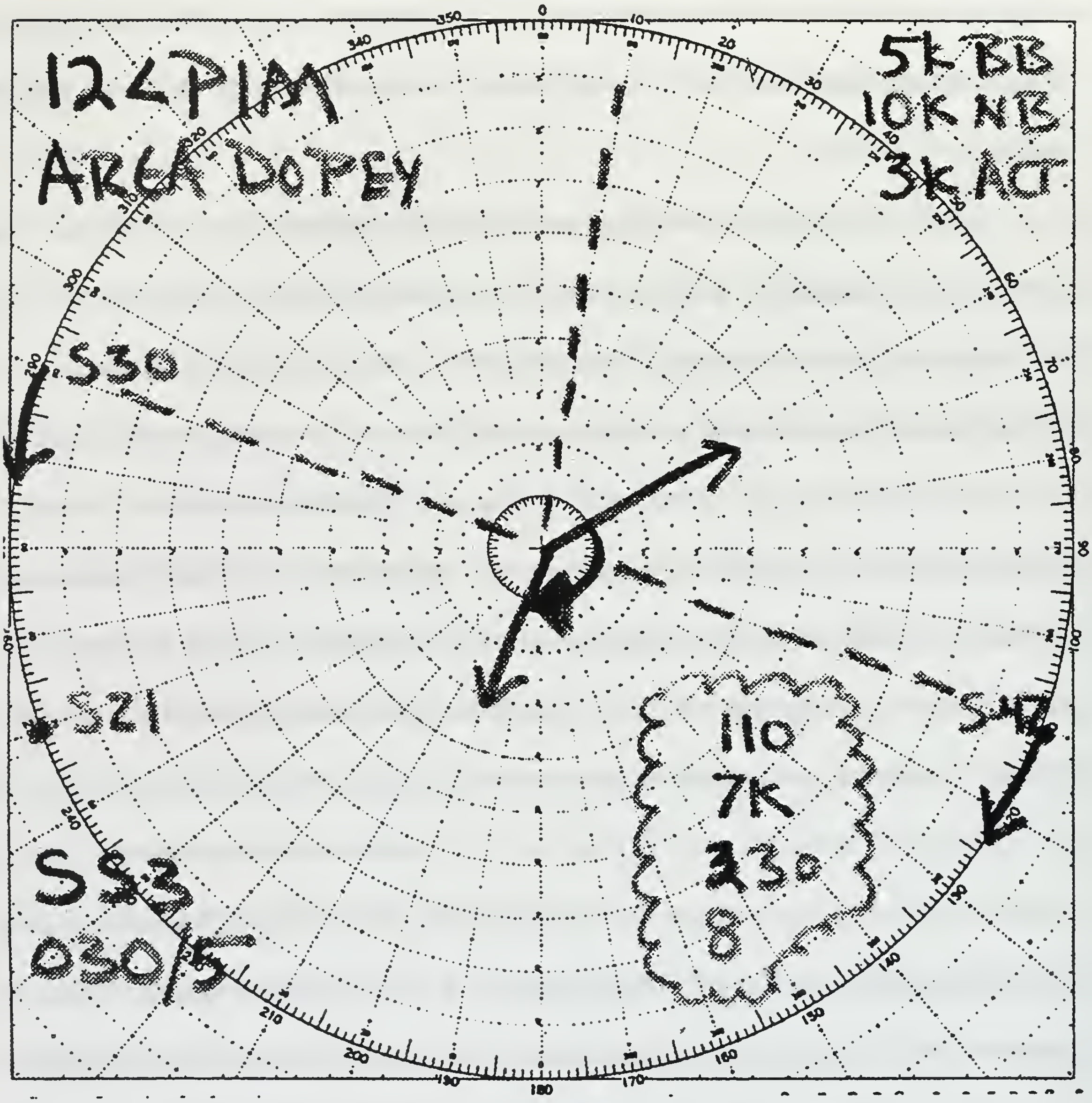

Figure 1.1 Typical AO Tactical Aid.

D. SCOPE, LIMITATIONS, AND ASSUMPTIONS

The present effort is confined to the evaluation of active duty U.S. Naval Submarine Officers in the use of a simulated CCS. Due to the simulator's low resolution, limits imposed on scenario run time, subject workload concerns, and military

classification, some realistic elements were impossible to incorporate. All subjects are assumed to be willing participants whose motivation is driven by pride and professionalism.

This paper is organized into five sections. First, the motivation for and objective of this research is described. Next, an in depth review of the literature supporting the objectives is presented. The methodology, which comprises both the experiment configuration and outcome generation, is described in the third section. The fourth section contains the results of exploratory analysis performed on the subject-generated database. The final section discusses the results and provides lessons learned and recommendations for follow on work.

II. REVIEW OF THE LITERATURE

Edwards (1988) defines Human Factors (HF) as the "technology concerned to optimize the relationships between people and their activities by the systematic application of the human sciences, integrated within the framework of human engineering." It attempts to integrate complex human performance concepts with statistical and stochastic methods to adequately capture the "man-machine" relationship. Because of the ambiguity involved, the study of HF has not gained universal acceptance. However, its benefits and contributions over the last 50 years cannot be disputed (Lederer, 1988). To provide a common core of HF terminology and concepts to the reader, a brief overview of Human Information Processing, Naturalistic Decision-Making, Situational Awareness, Schema Theory, Expert vs. Novice Performance, Display Design, and Link Analysis Techniques is presented. The military applicability of these areas is then used to address the core issues of this research.

A. HUMAN FACTORS CONCEPTUAL OVERVIEW

1. Human Information Processing

Human Information Processing (HIP) is the vehicle by which people decipher data. A principle feature of HIP models is the assumption that a series of stages or mental operations occur between external stimuli and self-directed responses. Much HF research is directed at isolating, and then characterizing each of these stages. Attributes such as capacity, duration, and representational forms of the particular stage are studied. While the end result remains elusive, there are several generally accepted models with the most widely accepted one being the Wickens and Flech (1988) Attention Resource Model (see Figure 2.1).

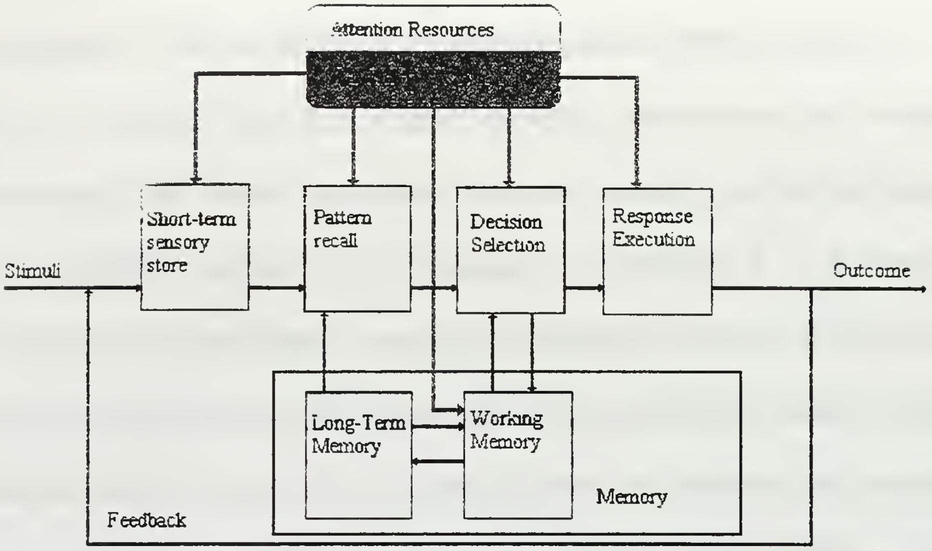

Figure 2.1 Attention Resource Model (Wickens & Flech, 1988).

The first stage of the Attention Resource Model, as depicted in Figure 2.1, is the Sensory Store. It is generally assumed that there is a separate sensory store for each sensory modality. In this store, the externally generated physical energy is transformed into internal neural energy and is represented in terms of its salient physical features. This information lasts only a brief time and does not require any attentional resources. While the first stage is relatively simple and uncomplicated, the second stage, Pattern Recall, is both the most crucial and least understood of all of the stages. It is at this stage that the physical stimulation in the sensory stores is integrated into meaningful elements. For example, the dark curved lines on this piece of paper are processed as meaningful letters and words. This process is very complex and is limited in its execution by the pool of available attentional resources. These patterns are typically stored in long term memory for later recall.

The HIP Attention Resource Model contains two distinct ways to store information: Working Memory, and Long-term Memory. Working memory represents the information currently being used by the information processor. The capacity of working memory is limited in both its scope and size. Long-term memory represents information available to the information processor, but not currently in use. Unlike working memory, long-term memory capacity is essentially unlimited.

The third stage, Decision Selection, is where a stimulus is recognized and a decision must be made regarding that stimulus. Various options are available at this point: the information can be stored for use at some future date, it can be integrated with other available information, or it may initiate a response. Each of these options generates their own associated costs and benefits that must be considered when choosing a single course of action. The decision generated in this stage is finally passed onto the last stage, Response Execution. In this stage, the selected decision is translated into a series of unconscious and conscious motor actions and sequences. The resulting outcomes, by way of a feedback loop, then become input to the sensory stores, which in turn can be interpreted and entered as relevant data in selecting the next response. As with the second stage, these final two stages are limited in their scope by the available attentional resources (Kantowitz & Sorkin, 1983).

2. Naturalistic Decision Making

In the early 1990's, there was a radical shift in the perception of human decision-making (Collyer & Malecki, 1998). The analysis of actual decision strategies that humans use in solving complex, real-world conditions was termed "Naturalistic Decision Making" (NDM) (Klein, 1993). "Naturalistic" psychologists assert that expert decision-

makers rarely use the traditional resource intensive strategies of classical decision-making in order to make decisions in the presence of complex, adverse, and time constrained scenarios. Rather, experts rely on internal heuristics formed by the very nature of being recognized system experts (Kozlowski, 1998). It is postulated that experts tend to recognize scenarios based on how closely the current situation matches one previously experienced (Kaempf & Militelo, 1992). The expert then recalls the previous actions taken in the stored scenario, evaluates those actions against the current situation, makes appropriate modifications within the current time constraints, and then activates the schema containing the actions. Rather than employing an optimization routine, the schema's activated typically pursue a *satisficing* strategy (Klein, 1993; Hutchins, 1995; Kirschenbaum, 1997). In other words, the expert selects a course of action which is not necessarily the best, but is still reasonable and will result in a outcome that is within the constraints of the situation at hand.

There are two models of decision-making currently used in “naturalistic” settings, Recognition Primed Development (RPD) and Explanation Based Reasoning (EBR) (Klein, 1993). RPD, more commonly known as feature matching, “occurs when the decision maker recognized the features of the present situation as similar or identical to those of a previous situation” (Kaempf & Militelo, 1992). An unconscious correlation then triggers the recall of all pertinent information learned about that particular situation: clues, cues, goals, expectations, plans of action, and outcomes that were observed in the past. Therefore, it is thought, expert decision-makers rely on detailed heuristics stored in long term memory to control decision making in similar, but different situations (Hutchins, 1996). EBR, more commonly known as story generation, occurs when the

decision-makers find themselves in complex situations without all the required information, the information is self-contradictory, and/or certain correlating events are absent (Bowers, 1998). The decision-maker then develops "neural links", or causal relationships, between facts to produce a working representation of the situation (Klein, 1993). Once constructed, the new model of the situation is acted upon by the decision-maker within the current environmental conditions.

Today, advanced Decision Support Systems (DSS) involved in such industries as nuclear power plants, off-shore oil platforms, and emergency service providers utilize a mixture of displays that support both RPD and EBR cognitive processing (Wickens, 1992). These displays, respectively, are termed "status" and "command". Status displays are characterized by their inclusion of "why" information and informs the user of what is known and assumed about the current situation. Status displays allow the user to examine differing hypotheses without committing to a specific course of action. This is in contrast to the "command" type display, which present information in list or bullet format and tells the user what to do without explaining the motivation behind the actions. This type of display is most often utilized in situations when quick responses are required of inexperienced or heavily tasked operators. The most common display type used for military decision support systems in the command display (Irizarry & Knapp, 1986). However, research indicates that by providing decision support in the form of a combination of command and status displays, an increase in the overall accuracy in the understanding of system and environmental states occurs (Kozlowski, 1998).

3. Situational Awareness

Enhancement in the understanding of system and environmental states is referred to as Situational Awareness (SA). For all current accepted models of NDM, SA is the sum and substance: sizing up the situation, understanding a scenario, defining the problem, categorizing the circumstances, constructing a representation, making mental models, painting a picture, or creating images (Federico, 1995). Decision-making in realistic settings is a process of not only producing and updating a representation of the perceived situation, but also specifying and appraising possible actions.

Unfortunately, perception, action appraisal, and mental choices are difficult to measure. However, since SA is the crux of user comparison, measures of effectiveness (MOE's) must be obtained (Federico, 1995). Typically in military settings, two approaches are taken in the measurement of SA. The first is the measurement of critical factors or preconditions that lead to, or inhibit SA. By the measurement of two secondary load factors, attention and working memory, the acquisition and interpretation of information from the environment necessary to form SA can be ascertained (Endsley, 1995). The second is the attainment of an objective MOE. This is typically measured in terms the military mind easily understands: minimum time or range, hit or miss, or life or death.

Of the current NDM models in use today, some link SA to the selection of action alternatives while others indicate that SA precedes and initiates the selection of action alternatives. Hammond's (1986) Intuitive Decision, Lipshitz's (1989) Matching Mode Decisions, and Rasmussen's (1983) Skill-based and Rule-based behaviors are all examples in which the perceived situation directly determines the chosen action.

Alternatively, Beach's (1990) Framing Action Selection Criteria, Connolly's (1982) Cognitive Mapping, and Klein's (1990) model of Critical Decision Making (CDM) are examples in which recognizing the situation precedes the determination of the chosen alternative.

NDM models as a group tend to emphasize certain salient cognitive processes that are associated with SA. Representing problems using knowledge structures or schema (Connolly, 1982; Beach, 1990), categorizing situations (Rasmussen, 1983; Klein, 1989; Lipshitz, 1989), and using storytelling or mental modeling (Hammond, 1986; Lipshitz, 1989; Beach, 1990) are some of the different methods espoused. However, the common thread running though all of these models is that the knowledge necessary to assess and recognize situations for NDM is incorporated into stored schema (Federico, 1995).

4. Schema Theory

Schemas are commonly defined as stored metal representations of previous experiences (Bailey, 1980). In other words, a schema is like an organized memory unit, similar to a stored computer program. These memory units can be stored and subsequently recalled using any of the five senses (Wickens, 1994). Once invoked, a schema is typically executed by a series of automatic and unconscious motor action sequences. For example, starting your car and driving to work, making toast for breakfast, or calling relatives on the telephone, are all examples of everyday tasks most people accomplish in an unconscious manner. An informal representation of the schema theory model is shown in Figure 2.2.

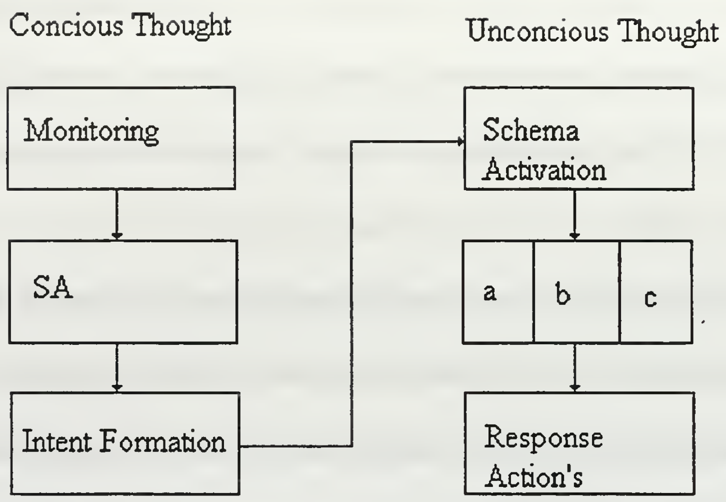

Figure 2.2 Schema Theory Model (NPGS School of Aviation Safety Handout).

In the current context of NDM, it is logical to infer that it is the stored schema that drives decisions. Consequently, this schema-driven decision making is primarily a RPD process. Stated differently, decision-making is comprised of recognizing previous scenarios and situations, the courses of action taken, and the eventual outcomes (Zachary, Ryder & Hicinbothom, 1998). It is postulated that entire patterns and sequences of events are employed in their entirety to facilitate recognition and assessment of similar scenarios. When similar situations are recognized or experienced, stored schema is activated, and past successful actions are applied to the present situation. This discussion is predicated on the notion that the decision-maker in fact, possesses the necessary schema in the form of neural-networked identification, action, and solution links. This assumption of correct mental representation and its correct employment, is the primary distinguishing trait of the so-called expert decision-maker. (Gick & Holyoak, 1983; Beach, 1990; Wickens, 1992).

5. Expert vs. Novice Performance

The core elements of expert vs. novice distinction and subsequent performance implications have been the subject of numerous investigations (Federico, 1995; Glaser, 1985; Klein, 1993; Wickens, 1992). These observations have been drawn from the analysis of decision-makers that routinely operate under conditions of extreme time constraints and stress: emergency room doctors, aircraft pilots, nuclear plant operators, etc. When taken as a group, the observations of previous researchers seem to share several important aspects: 1) experts tend to excel primarily because they possess extensive knowledge in their respective areas, 2) experts distinguish patterns in task execution that indicate superior knowledge organization skills, 3) experts perform tasks quicker with less errors, 4) experts process superior STM and LTM, 5) experts perceive and categorize situations at a deeper and more principled level, 6) experts initiate and maintain correct mental representations of the situation and inherent constraints at hand, 7) experts posses superior self-monitoring skills when checking for errors, 8) experts spend proportionally more time building the basic problem description than seeking solutions, 9) experts possess a larger set of stored schema, and 10) expert knowledge is structured, organized, and inter-linked to a greater degree (Glaser, 1985; Glaser & Chi, 1988).

Expert knowledge, however, has been shown to suffer from severe biases that inhibit proper decision-making. Experts as a group tend to have difficulty in responding to feedback and shifts in the nature of the situation after a course of action has been executed. Problems with misleading feedback, limited attention to delayed feedback, selective perception of feedback, and selective influence on outcome have been

conclusively shown in studies (Wickens, 1993). Novices, due to their lack of pre-conceived notions and institutional biases, tend to react better to ever changing environments.

The results from these investigations of skilled behavior all demonstrate that fundamental differences exist between expert and novice decision-makers regarding knowledge structure, pattern perception, performance speed and accuracy, memory capacity, and problem perception. Once identified, these differences cannot only be capitalized upon, but if necessary, corrected through selection methods, training regiments, or system modifications (Howell, 1998).

6. Display Design

Since it is the man-machine interface that most users are concerned with, the question is now: How does the interface designer account for and exploit differences in the varying levels of user proficiency? Once the appropriate mental model of the user has been constructed, how does a designer go about the construction of a new interface/display? What principles do they rely on to ensure the user derives maximum benefit? In general, a display's effectiveness is the functional combination of five specific and distinct attributes: Legibility, Readability, Accuracy, Compatibility, and Timeliness (Bailey, 1980).

Legibility simply means that the display can be easily read. A detailed knowledge of typefaces, letter sizes, spacing, etc., all come into play. If the display is illegible, it will fail to communicate needed information to the user, and all of the other characteristics will become useless. Legibility, however is not an absolute property (Meister, 1965). Both the external aural and visual environment affects its use.

Readability implies that the display communicates well, and the user perceives, without effort, the meaning or purpose of what is being presented. This in turn implies either an equal level of expertise among users, or a display that can adapt or differentiate amongst users. Readability is also achieved in part by having the appropriate sequential order of presentation, or grouping of information, to the user (Ramsey & Atwood, 1979).

Accuracy is a double-edged sword. On one hand, the display must be designed to elicit accurate information from the user. Instructions or headings that are vague, ambiguous, or misleading may result in inaccurate entries by the user. On the other hand, the display must transmit accurate information to the user (Wickens, 1992). Failure to do so might result in the formation of inaccurate hypothesis and the subsequent incorrect courses of action.

A display must be compatible with the user's knowledge and skill, other concurrent activities being performed, and again, the working environment in which it is being used. Compatibility is perhaps the most important factor in both performance and acceptance by the user. Experience has shown that sometimes systems fail not for technical reasons but for reasons of user acceptance (Engel & Eruda, 1975). The common sense remedy to ensure compatibility and cultivate user acceptance is to clearly establish user requirements early in the developmental process, and then ensure that the new displays adequately reflects these requirements.

The final attribute in display design concerns the timeliness of the data built in and presented by the display. In simple terms, the display must present information available to the user while it is still useful. Processing or compiling (to use computer jargon) delays are to be avoided in any low-ordered system. Also, a well-designed

display should present only essential information in such a form as to require only a minimum amount of interpretation (Bailey, 1980). Information, just for information's sake, has no place and only serves to confuse the operator.

7. Link Analysis

In addition to the five factors of good display design, two more issues should be addressed. They are the concepts of Grouping and Standardization. Grouping techniques are instrumental in helping to organize information and are comprised of four fundamental traits: Sequence, Frequency, Function, and Importance. Standardization techniques assure that information is presented in compatible sensory modes and that they do not conflict with any preconceived notions and/or biases held by the users. (Bailey, 1980).

Link Analysis groupings all share the same core principle: items should be grouped together based on their relative relationship to each other (Bailey, 1980). This relationship can be defined in terms of sequence of use (i.e. left to right and top to bottom), frequency of use (i.e. bivariate normal distributions of item location in the display), functional allocation (i.e. changing the layout of the display based on operating mode required by the user), and importance placement (i.e. placing critical items in the best position on the display to insure that they are not overlooked). Each type of grouping lends itself to different data collection methods. Sequential relationships are identified by using a process called procedural flow analysis. Frequency analysis is accomplished via a process called link analysis. Functional and Importance relationships are most often determined by a combination of historical, procedural, and subject operating methods and modes (Chapanis, 1959). Each type of Grouping has its

contribution to make, and it is the designer's task to undertake a deliberate process of elimination, weighting, and judgment to arrive at the "best" possible design. When conflicts arise, as they are wont to do, the designer must give the highest precedence to meeting human performance requirements above all others.

Standardization itself is comprised of two types: standardization of items on a specific display and standardization of display format (Bailey, 1980). Standardization of items refers to the goal that all items in the system with the same information should have the same modality. This modality includes not only its name, structure and physical appearance, but also its encoding algorithm. Standardization of display format is the principle in which the interface designer attempts to place items that appear on multiple displays in the same geographical location on all displays. This intentional placement reduces the workload on users by allowing the user to capitalize on "location" memories (Davis, 1966). Although standardization is desirable, it should not take precedence over the grouping principles described earlier.

As stated before, there are several avenues that facilitate proper human factor data collection techniques: Procedural Flow Analysis, Articulation Testing, Critical Incident Analysis, Time Line Analysis, and Link Analysis just to name a few. Each method is used to address similar, but very specific questions. The latter, link analysis is the observational technique for determining the relative association among system components or elements (Bailey, 1980). The results of link analysis are typically expressed in either frequencies or probabilities. The textbook application of link analysis is the "office desk arrangement problem" (Chapanis, 1959). In this situation, the office layout designer is concerned with arranging the desks of several employees in order to

facilitate the greatest communication with the minimum movement of employees. Data is collected on the number and distribution of interactions between employees and a seating arrangement then evolves. However, elementary applications of link analysis do not take into account issues of time partitioning, usefulness, or hierarchical associations among subjects. Therefore, link analysis is best used when determining the layout and arrangement of people and machines in systems, as well as the displays they employ.

B. MILITARY APPLICABILITY

1. Submarine Approach Methodology

Regardless of a submarine's operational tasking, successful units provide the CO with quick and accurate information on all contacts. The task of correlating and transforming the available raw data into the necessary picture is borne by the AO (Clancy, 1997). The AO performs the role of senior decision-maker and advisor to the CO during an encounter with a hostile target.

Information provided to the AO is, unfortunately, cryptic and uncertain. The AO will never be able to confirm theories directly, but may only observe how closely reality conforms to them (Clancy, 1990). The AO hunts an enemy submarine that is most likely also hunting for him. Unlike other modern forms of combat, the AO has no visual contact with an opponent. The medium of the ocean inhibits visual utilization to only a few feet (Sharpe, 1998). Rather, those that operate under the sea utilize aural information exclusively.

A useful analogy of the AO's task would be the hypothetical situation of two blindfolded prizefighters in a boxing ring. In the ring, each fighter seeks the other and each has a brutal power punch available to use if necessary. However, they are not alone

in the ring, as innocent non-combatants (referee, trainers, scorecard keepers, etc.) and even the occasional domestic animal wanders occasionally about. Fortunately, each knows the approximate layout of the ring, i.e. the location of the ropes, stools, and other distinguishing traits. During his search, each relies on his own aural abilities to identify other wanderers, decide whether they might be the opponent, and attack if within range of a punch. Still, simply detecting the enemy does not imply the ability to hit him. First the fighter must roughly decide the distance of the enemy, using the level, pitch, and directivity of the noise. Once the enemy range is identified, the fighter must approach his opponent, within effective striking range, remembering that the chances of being counter-detected increases each second. Using similar, but somewhat more complex methods, the fighter also determines the enemy's moving direction and speed. Once the fighter is satisfied that the enemy's "solution" has been determined, a punch is thrown, and then the fighter quickly retreats to avoid the enemy's counter-punch, which will assuredly be thrown in response. A successful engagement will find the fighter safe, his opponent dispatched by a wicked right cross, and no enemy counter-punch contacting the fighter due to some suicidal last effort.

Even the forgoing discussion simplifies the role of the AO considerably. Physics presents difficult challenges in a real scenario; e.g. sound does not travel in straight lines, rather it bends and bounces as it travels through the ever-changing ocean medium (Sharpe, 1998). Received sound has often been reflected off the bottom or surface of the ocean, so the source lies not on a line but instead a hyperbola opening behind, or in front of, the sensor. The phenomena of Convergence Zones, Ducting, Shadow Zones, Arrival Paths, and Limiting Rays, just to name a few, even further mire the situation. This

discussion is only intended to give some idea of the various tasks and concerns the AO faces during a submerged approach.

2. Previous Research

Due to the inherently secretive nature of submarine design and construction, there is a noticeable absence of unclassified human factor analysis in the submarine community. Previous work has shown that naval officers engaged in Anti-Submarine Warfare (ASW) and Anti-Surface Warfare (ASUW) show a pre-disposition to data representation in analogical, or geo-situational, frames of reference (Kirschenbaum, 1995; Hooper, 1994). In addition, it has been shown that while senior ASW decision-makers strive for optimality in their endeavors, certain inherent and specific cognitive limitations and biases prevent this: they include 1) working memory limitations, 2) a bias toward overestimation of enemy submarine maneuverability, and 3) a bias toward overestimation of sonar accuracy (Wohl, 1989).

There is a wealth of research on human factor analysis concerning aviation issues, and to a lesser extent, military decision-makers in general. Several texts (Wickens, 1992, Wiener & Nagel, 1988, Pruitt, 1982) give excellent examples of the depth and breadth of HF aviator work. The cognitive link between aviators, surface warfare officers, and submarine AO's was established by Hooper (1994), and is used as an anchor for the principles applied in the course of this research. It is in fact reasonable to assume that, in general, military decision-makers all share the same cognitive abilities and limitations.

3. Current Research

Unlike the multitude of research projects underway in aviation areas, the only major unclassified submarine related human factor analysis project currently under works

is Project NEMO (Kirschenbaum, 1997). Early work in project NEMO has concentrated on examining the goal and sub-goal structure of a small cadre of senior submarine AO's. Preliminary results indicate a very shallow goal structure, as well as a bias toward analogical schema orientation. Secondary results indicate a possible limit on both the short term and long term working memory of AO's that must be acknowledged and exploited. Current work surrounds expert vs. novice issues as well as preliminary display resolution concerns. Future work is slated for building a complete cognitive model of the submarine AO (Kirschenbaum, 1997).

C. SUMMARY

The issues presented are indeed complex, but manageable. Current HIP models, NDM paradigms, SA measurement methods, Expert vs. Novice distinctions, and their implication in modern DSS design have been applied to military settings successfully in a variety of areas (Howell, 1998). Most notably, the construction of TADMUS and most modern military aircraft cockpits. Only recently however, have issues related specifically to submarine man-machine interface been freely discussed.

The applicability of the forgoing discussion to the AO task can be summarized as follows. By acknowledging and operating within the limitations inherent in the HIP model, it is postulated that AO's employ the NDM paradigm for decision-making in high-stress environments. Measures of AO SA, built in response to stored schema fostered during in the course of initial and periodic training, differentiate between levels of proficiency and skill. These levels are typically correlated to the established designation of expert vs. novice. After revealing these expectations of proficiency, data analysis on AO informational usage can be utilized in the prediction of future success and the

construction of tools, i.e. displays, that have the potential for improving the AO's ability to execute their primary task, i.e. to search out and destroy an adversary. These same tools can also be used as a selection and training aid in the course of an AO's professional development.

III. METHODS

A. RESEARCH APPROACH

This research involves the analysis of a human performance database collected during the employment of a Submarine CCS Simulator. The database contains both numerical data regarding the use of different displays and information available in the simulator as well as specific background data on the test subjects. Statistical regression techniques determine which demographic variables can be used to predict the quality of an engagement. Trends in data usage among subject groupings are identified and then used as inputs for the design of the next generation Submarine CWS.

B. DATA COLLECTION

1. Subjects

Qualified active duty Submarine Warfare officers of varying experience, as measured in years of Naval service and sea service participated in the study (See Table 3.1). They represent approximately 10% of the total available pool of U.S. Navy AO's. Subjects trials were conducted in the Operations buildings of NSB Pearl Harbor, HI and NSB Bangor, WA during period of May 18th to June 4th 1998. Subjects were briefed on the purpose of Project NEMO and provided informed consent in accordance with the ethical conduct for subject participation specified in the Protection of Human Species, Secretary of the Navy (SECNAV) instruction 3900.39b (See Appendix B).

YEARS	MEAN	STD DEV	MIN	MAX
NAVAL SERVICE	13.22	5.10	5.00	23.00
SEA SERVICE	6.26	2.92	1.50	14.00

Table 3.1 Subject Experience.

2. Apparatus

A Macintosh PowerBook 2400c/180 (603E) equipped with an 11.1" active matrix screen presents the stimulus. Subject interaction with the simulation, to include vocalization, is recorded via a PC-to-VCR s-port adapter, a Sony HI-8 TR9 camcorder, and a lapel microphone. Subjects are seated in front of the computer and are allowed free movement during the testing. Figure 3.1 shows the equipment configuration. To avoid any possible distraction, the entire apparatus, with the exception of the laptop and mouse, is covered with an opaque black cloth.

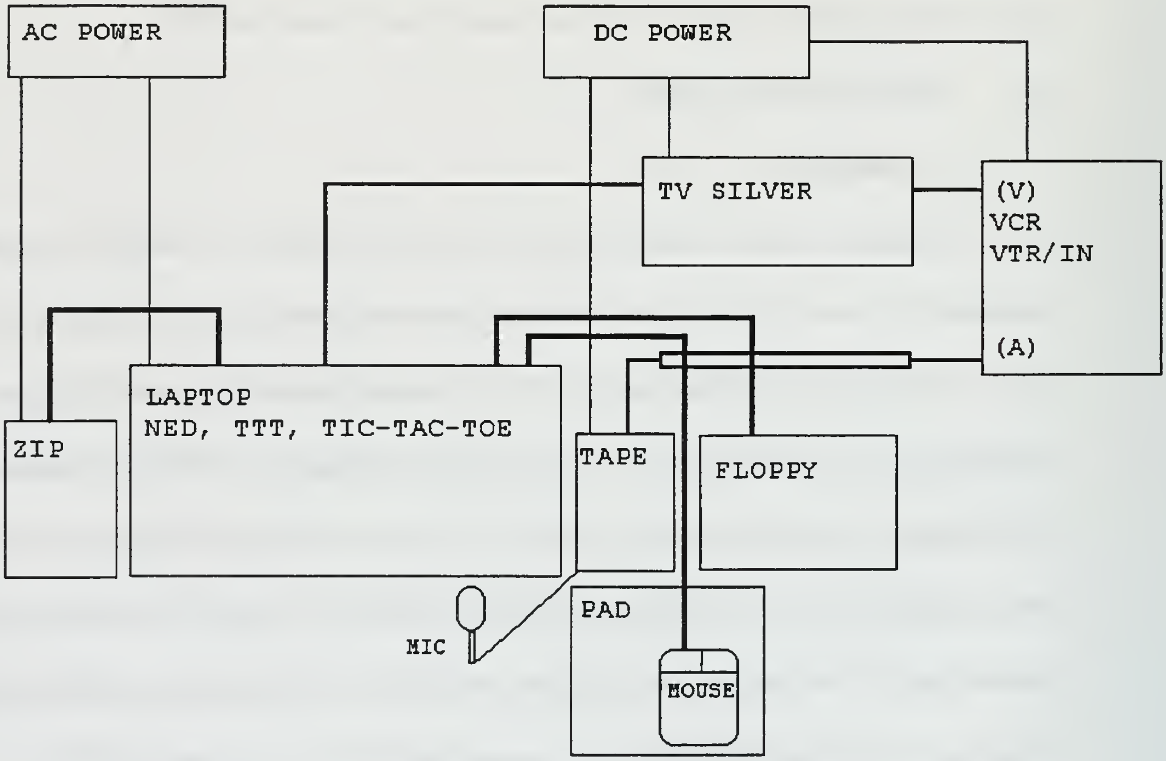

Figure 3.1 Experiment Equipment Configuration.

3. Stimulus

The simulation mimics the current tactical displays onboard a generic U.S. submarine. Ten separate displays are presented; OwnShip-Control (OSC), Sound Velocity Profile (SVP), Line of Sight (LOS), Geo-Plot (GEO), Time-Bearing (TB),

Time-Frequency (TF), Spherical Array Passive BroadBand (SAPBB), Towed Array Passive BroadBand (TAPBB), Towed Array Passive NarrowBand (TAPNB), and Primary Mate (MATE). The simulation contains one practice and four actual test scenarios. The four scenarios are representative of the expected tactical encounters for which U.S. AO's train. However, the difficulty of the scenarios is purposely skewed toward the easier side in order to facilitate increased user interaction. The simulation language is Mac Common LISP.

4. Instrument

The instrument consists of two elements. The first is the layering of a MSExcel OLE compliant recorder underneath the stimulus. Informational use by the subject is recorded by what is referred to as a "poor man's eyetracker." This instrument works in the following manner: 1) Each display is accessed individually by use of a vertical task bar on the side of the "master" display. 2) All information on the displays is normally covered by the use of "black boxes" generated by simulation. To view a piece of information on a specific display, the subject places the computer-generated cursor over the display area to be examined and depresses a button. Once the button is depressed, the black box for that specific piece of information is removed and the subject is allowed to view the requested information. 3) The information is displayed only as long as the cursor is held steady. Layering the recorder under the stimulus allows for the archiving of the events that occur during the course of the experiment. The archived data for each subject trial is then stored for future examination. The second instrument is a small survey questionnaire designed to measure subject satisfaction as well as the perceived difficulty and fidelity of the stimulus. The survey also measures the subject utilization of

actual CCS displays and provides an avenue for subject input to the CWS design. (See Appendix D)

5. Procedure

The protocol guides the interviewer through the process of subject identification, indoctrination, testing, classification, and subjective evaluation. Subjects are identified by the interviewer via a sequenced 3-digit number and that number is used throughout the remainder of the testing process. Subject indoctrination consists of two phases. First, subjects view a short, 60 second, computer video on how to play a tic-tac-toe game in which the computer verbalizes it's thoughts and actions. Next, they are allowed to play the same tic-tac-toe game and are instructed on how to verbalize their own thoughts and actions. They are then instructed to continue verbalization throughout the remainder of the testing process. Next, subjects are taken on a "guided tour" of the simulation by the interviewer and instructed on how the simulation works. A short, 15-minute, free-play period then ensures that the subject is "comfortable" with the actual operation of the tactical simulation. The testing phase commences with each subject receiving the same mission statement shown in Figure 3.2.

MISSION

"The world situation is that a war has broken out between Russia and Ukraine over control of the former Soviet Navy. Both nations are trying to get the US involved and have been attacking U.S. shipping with submarines and then blaming each other. You are patrolling in the eastern Caribbean Sea. Your mission is to protect U.S. shipping lanes. Your orders are to search and destroy any enemy submarines in the vicinity of U.S. shipping. The month is April and the sea state is 2."

Figure 3.2 Mission Statement.

Each subject attempts to complete two of the four available scenarios. Each scenario starts with a status report similar to that shown in Figure 3.3.

> STATUS REPORT
>
> "You hold one merchant bearing 300 degrees, but no subsurface contacts. The broadband range of the day for a subsurface contact is 3-6 thousand yards. Intelligence has indicated an Alfa-type Formerly Soviet Submarine is patrolling in the area. There are no friendly submarines in your patrol area."

Figure 3.3 Status Report.

The four initial contact scenarios differ only in initial contact bearing, course and speed. The number of contacts and intelligence report remains the same throughout the experiment (See Appendix C).

At the conclusion of the testing phase, the subjects provide background data on themselves and complete a subjective evaluation of the simulation. The final step is the subjective design phase. At this time the subject is asked to produce a sketch of what the subject "wants" on the next generation of Submarine CWS if they were the one in charge. Discussion is encouraged during this time with the tester as to facilitate creativity and innovation (See Appendix B for the full protocol).

6. Experimental Design

A 3 x 2 x 4 modified Latin square design is used in the experimental protocol (See Appendix C). The three refers to the 3 levels of operator proficiency (Expert, Mid, Novice). The two refers to the run order (First vs. Second) of the two scenarios presented. And the four refers to the designation of the scenario (C1, C2, Z1, Z2) presented. The modified design was chosen because the distribution of the subject proficiency was not known in advance of the data collection. This structure allows for a

balanced design across the levels of subject proficiency, presentation order, and target scenario.

C. DATA ANALYSIS

1. Data Generation

Five events are recorded by the first element of the instrument: the specific display viewed, the specific information viewed on the display, the total time spent viewing the information, any inputs the subject made to the simulation, and the time at which the viewing of or input to the specific display occurred. Each event is stored as a separate line of ASCII data and the scenario in total is stored as an individual computer file. The instrument's second element, the survey questionnaire, consists of four closed-end and three open-ended questions. The four closed questions measure scenario realism, scenario difficulty, display effectiveness and display utility. Three of the closed questions use a 5-choice Likert scale while the last uses a 10-choice ordinal ranking layout. The three open questions measure overall subject response to the experiment, subjective desires for CWS attributes, and general feedback. The questionnaires are completed by the subjects in the presence of the interviewer.

2. Data Tabulation

The computer generated ASCII files are first individually converted into an MS Excel spreadsheet and a Visual Basic (VB) Macro is applied (See Appendix F). The individual trial spreadsheets are combined together with the survey responses and then all of the data is merged to form a "master" spreadsheet which is organized by both subject and trial number to facilitate statistical analysis by demographical as well as scenario distinctions. The master spreadsheet is available in both MS Excel and SPLUS formats.

3. Variable Description

The predictor variables are of two categories: one, demographic variables describing the subjects, and two, CCS display usage patterns and subject survey results. Subject demographic variables include six categorical variables: Position (POS; 1-Expert, 0-Novice), Ship Type (TYPE; 1-SSN, 0-SSBN), Geographical Location (LOC; 1-Pearl Harbor, 0-Bangor), Duty Type (ROT; 1-Sea Duty, 0-Shore Duty), Level of Education (EDU; 1-Masters/Ph.D., 0-BS/BA), and Scenario Completed (SCEN; 1-C1/C2, 0-Z1/Z2). The display usage variables are functions of four basic variables: the number of display accesses, the total time of display use, the average time of display use per access, and the standard deviation of time of display use per access. These four variables combined with the survey results produce 92 distinct display usage variables. The demographic and display usage variables are extracted from the original ASCII files by use of the previously mentioned VB Macro.

The response variables take the form of two continuous objective and one binary subjective MOE's. The two continuous objective measures are solution accuracy at time of fire (TOF) and weapon to target closest point of approach (CPA). To obtain an objective measure of accuracy at TOF, the absolute distance between the actual target location, as recorded by the simulation, and the perceived target location, recorded as the firing solution of the subject just prior to TOF, is computed. To standardize the geometry across all subjects, a 2-D grid is superimposed on the engagement area with the AO at the center (0,0) and the targets, actual and perceived, identified by their relative positions on the grid. This error, termed Composite Error (CE) is given in Equation 1.

$$CE = ((Xa-Xp)^2+(Ya-Yp)^2)^{1/2} \text{ [yds]} \qquad \text{Eqn. (1)}$$

where,

(Xa, Ya) : Actual target position [yds] on the 2-D grid

(Xp, Yp) : Perceived target position [yds] on the 2-D grid

The calculation of weapon to target CPA is determined via a two-stage process. First, the final firing solution is extracted from the simulation and the appropriate weapon kinematic parameters are generated. The weapon is assumed to be a standard U.S. Navy MK-48 mod IV Heavyweight Torpedo (See Appendix E). From there, a GAMS simulation determines the actual torpedo to target CPA (See Appendix G) in terms of the CPA range (R_{CPA}) and CPA time (T_{CPA}).

To obtain the subjective assessment of subject performance, three factors are examined: torpedo to target CPA, AO exposure, and time of engagement. These three factors answer the following questions. First, would the final solution have resulted in a HIT? Second, did the AO minimize own-ship's EXPOSURE to counter-detection by the opposing submarine? And third, did the AO, upon achieving a "good" firing solution, realize that the engagement could end at that time and thus minimize the TIME of the engagement? It is assumed that if all three factors are within the acceptable ranges, the engagement as a whole would be successful, i.e. the scenario resulted in the destruction of the enemy and the survival of own ship. If any one is outside the prescribed range, then the engagement as a whole would be considered unsuccessful, i.e., the scenario resulted in the survival of the enemy and/or the destruction of own ship.

The notion of the AO getting a weapon hit is the first factor examined. A HIT is defined to have occurred if the final solution generated weapon parameters would have

resulted in an impact with the enemy. This factor, classified as a 1 for an impact and a 0 otherwise, is determined via a two-stage process. First, the final firing solution entered by the subject is extracted from the simulation. And second, as with the determination of CE, the appropriate CPA parameters are generated. If the CPA range is less than acoustic acquisition range for the torpedo (2000 yds) and the CPA time is within the weapons run time (3500 sec), the weapon is assumed to impact the target.

AO exposure is the next factor examined. EXPOSURE, in this case, is defined as the minimum range experienced by the AO during the course of the engagement. Two factors are used in determining a cutoff threshold. First, it is assumed that the enemy is pursuing the AO and while it is assumed that the AO has an acoustical advantage, the chance of counter-detection increases as exposure decreases. Second, to coin a movie phrase, "the problem with submarines is that they do not turn on a dime" (Clancy, 1990). The point being that, as two submarines get close to one another, the risk of collision is just as important as the risk of counter-detection. For these two reasons, a lower limit of 2000 yards is placed on EXPOSURE. If the AO to enemy range is greater than 2000 yards for the duration of the problem, a 1 is recorded and if not, a 0.

The time required to get a solution is the final factor examined in determining overall solution quality. While longer engagements can lead to more accurate solutions, they also increase the danger to the AO. Remember that while the AO is pursuing the enemy, the enemy is also pursuing the AO. Hence the danger of counter-detection by the enemy, and resulting counter-fire, increases as the AO spends more time in the vicinity of the enemy. A perfect solution obtained after the enemy has disengaged or while getting shot is of no value. Therefore, to account for this, a TIME constraint of 1500 seconds is

used to identify the point at which counter-detection and eventual counter-fire might occur by the target. If the AO initiated a firing prior to this time, a 1 is recorded and if not, a 0.

These three factors: HIT, EXPOSURE, and TIME are combined to determine if the engagement is a success. If all three factors are a 1, the engagement is a success and a 1 is recorded for the variable SF (success/failure). If any of the factors is a 0, then the engagement as a whole is a failure and a 0 is recorded for SF.

4. Statistical Analysis

To analyze and compare the performance of the subjects, a two pronged approach is used. First, performance is studied as a function of the subject demographic variables. For this, the two MOE's, CE and SF, are used. Classical logistical regression (Hamilton, 1992) and CART analysis (SPLUS, 1996) compromise the bulk of the data analysis techniques employed. The second prong will explore differences in display usage and solution generation strategies of the subjects as a function of the demographic variables. This approach is shown in Figure 3.4.

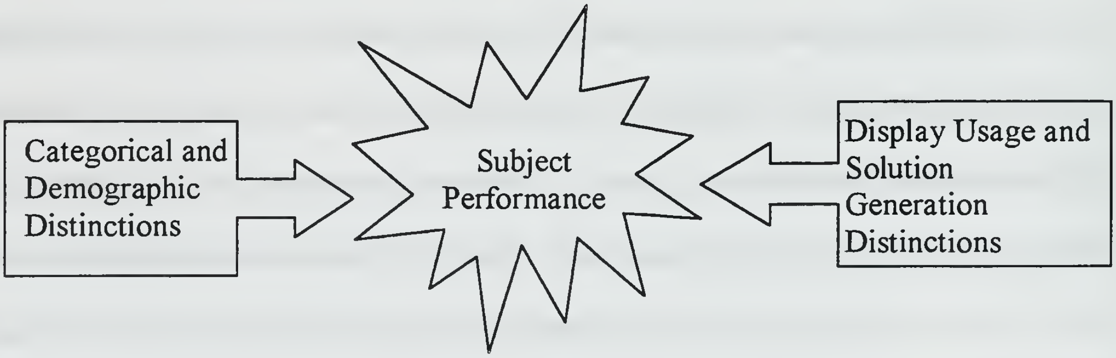

Figure 3.4 Data Analysis 2-Prong Approach.

The display design process will utilize a three pronged approach. First, the subject survey evaluation of the effectiveness and usefulness of the current CCS displays

(See Appendix D) as measured by the mean response will be extracted. Second, link analysis techniques will extract the display usage and solution generation patterns of the "best" group of AO's as distinguished by distributional and categorical relationships previously identified. And third, the top ten salient issues generated by subject feedback when asked of their desires for the next generation of CWS (See Appendix D) will be used as the final input. These three inputs will then be merged into a comprehensive layout and set of display attributes for the final CWS. This design methodology is shown in Figure 3.5.

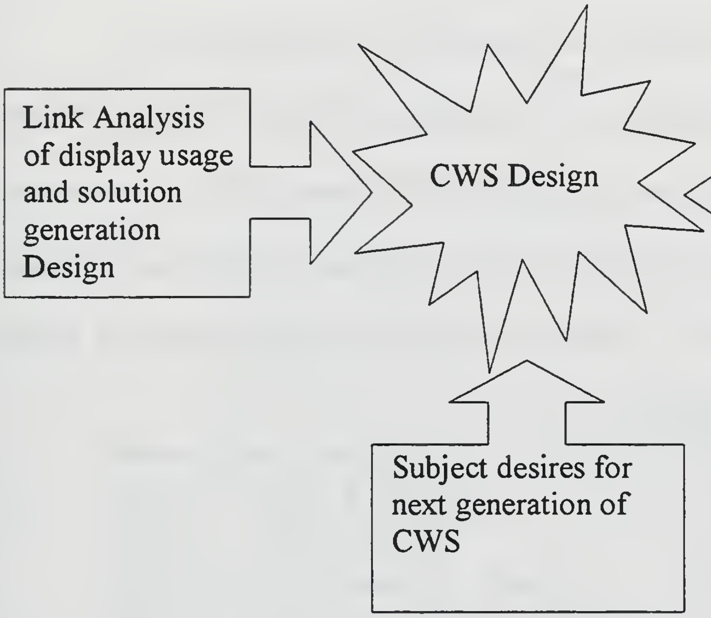

Figure 3.5 Display Design 3-Prong Approach.

IV. RESULTS

The analysis conducted in this research is primarily exploratory in nature. Over 100 hours of experimental data is utilized in the creation of a subject performance database. From the database, the variables most indicative of subject performance are extracted and used as the basis for analysis. Any subject modeling or statistical analysis results obtained will need to be verified by an independent study prior to drawing any final conclusions.

A. TRIAL RESULTS

The subject pool for the experiment consists of 49 volunteers. Of these, 36 subjects correctly finished the testing protocol resulting in 65 completed trials. Even with the exclusion of 26 percent of the experiment participants, the use of the modified Latin square design for the remaining 65 trials succeeded in partitioning the subject pool fairly evenly according to the 6 demographic variables. This is shown in Table 4.1.

Demographic Variable	Variable = 1	Variable = 0
	n (%)	n (%)
POS (1 - Expert, 0 -Novice)	27 (42)	38 (58)
TYPE (1 - SSN, 0 -SSBN)	33 (51)	32 (49)
LOC (1- Pearl Harbor, 0 – Bangor)	28 (43)	37 (57)
ROT (1 – Sea Duty, 0 – Shore Duty)	50 (77)	15 (23)
EDU (1 – MS/MA/PhD, 0 – BS/BA)	34 (52)	31 (48)
SCEN (1 – C1/C2, 0 – Z1/Z2)	33 (51)	32 (49)

Table 4.1 Subject Pool Partitioning by Demographic Variables.

Subject responses to the issues of simulation realism and scenario difficulty are first examined to verify the original mandates of simulation fidelity and ease of use. As is shown in Figure 4.1 and 4.2, the frequency histograms of Realism and Difficulty are right-skewed, with a median of four and a mean of 3. With the scales used, i.e. 1-Very

Difficult/Unrealistic and 5-Very Easy/Realistic, the results indicates that, as a group, the subjects rated the simulation as realistic and fairly easy to use.

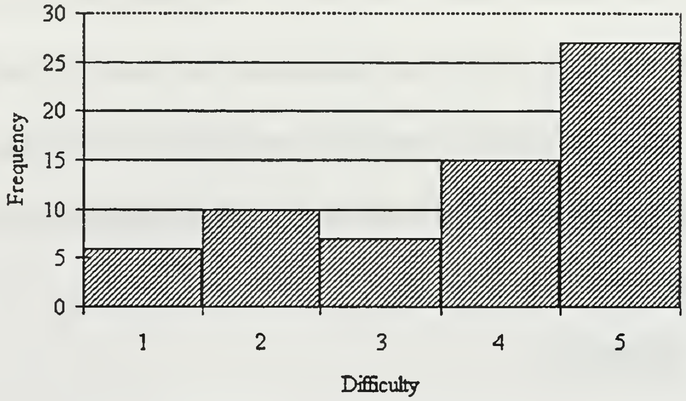

Figure 4.1 Histogram of Scenario Difficulty (1-Very Difficult, 5-Very Easy).

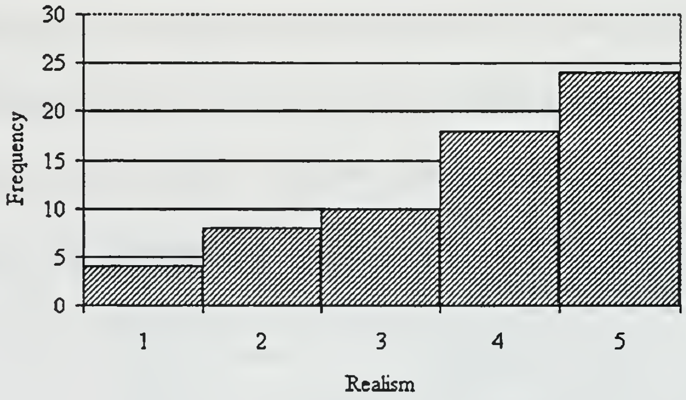

Figure 4.2 Histogram of Scenario Realism (1-Very Unrealistic, 5-Very Realistic).

B. MOE RESULTS

When analyzing and distinguishing the performance of the subjects, the earlier defined two pronged approach is used. The distributions of the MOE's, CE and SF, along with CPA, EXPOSURE, and TIME, are examined first in an attempt to understand the underlying relationships between the MOE's. Excluding TIME, the distributions indicate

that the subjects performed within the ranges of values expected. The distribution of TIME, however, did not reveal the expected bias toward shorter engagement times.

The distribution of CE is shown in Figure 4.3. As can be seen, the frequency distribution of CE is heavily left-skewed with most subjects having a low CE with a median of 1291 yds and a mean of 1386 yds. This indicates that most subjects arrived at a reasonably accurate solution at TOF.

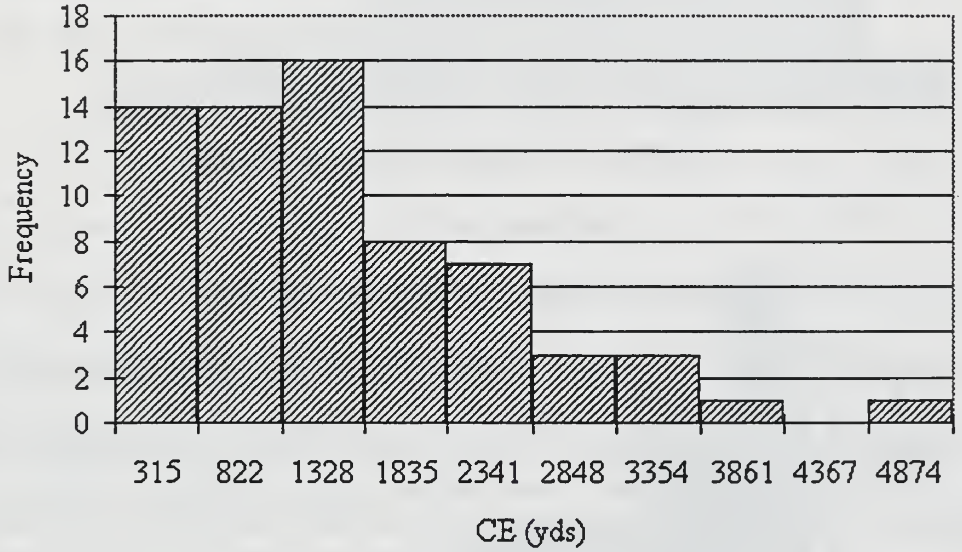

Figure 4.3 Frequency Histogram of CE.

The distribution of the weapon to target CPA parameters, T_{CPA} and R_{CPA}, are shown in Figure 4.4 and 4.5. As can be seen, the frequency distributions are left-skewed (median(T_{CPA}) = 127 secs, mean(T_{CPA}) = 146 secs; median(R_{CPA}) = 248 yds, mean (R_{CPA}) = 391 yds) indicating most subjects made limited use of the torpedo's capabilities at TOF. Rather it seems that the subjects preferred to rely on a more accurate solution (i.e. a low CE) at TOF.

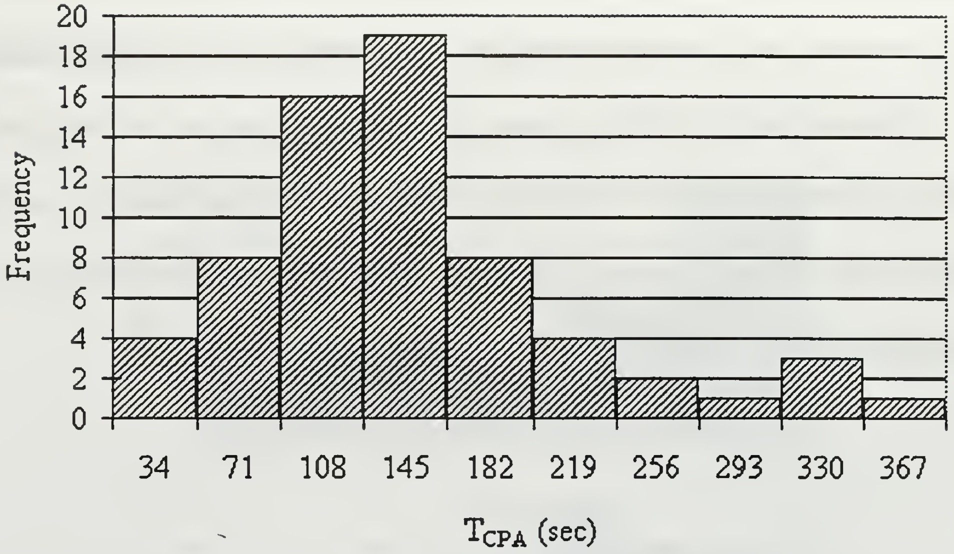

Figure 4.4 Frequency Histogram of T_{CPA}.

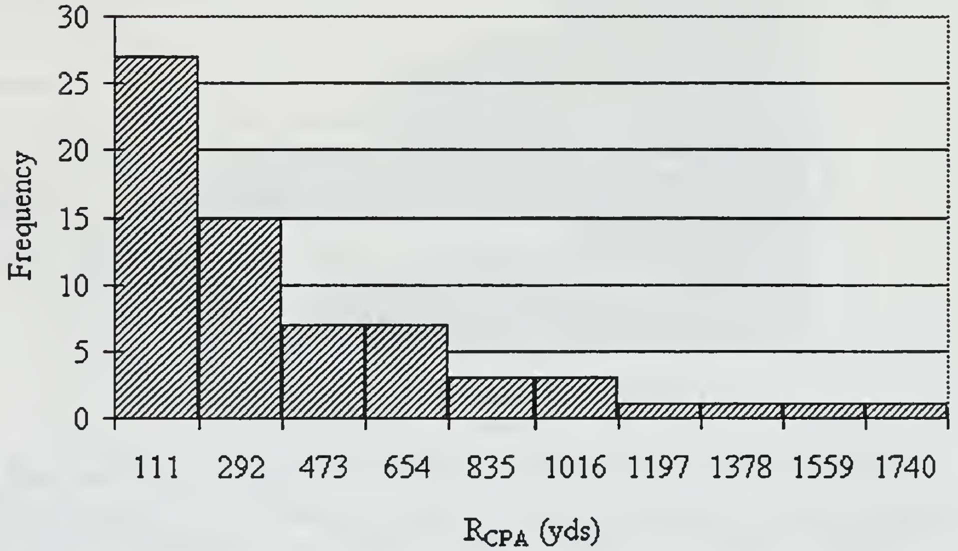

Figure 4.5 Frequency Histogram of R_{CPA}.

The distribution of exposure is shown in Figure 4.6. As can be seen, the frequency distribution of exposure is lightly right-skewed with a median of 4000 yds and a mean of 3903 yds. This indicates that most subjects had a high exposure. This is consistent with the expected results in that most subjects should have made a concerted

effort not to get too close to their adversary and therefore risk counter-detection and/or collision.

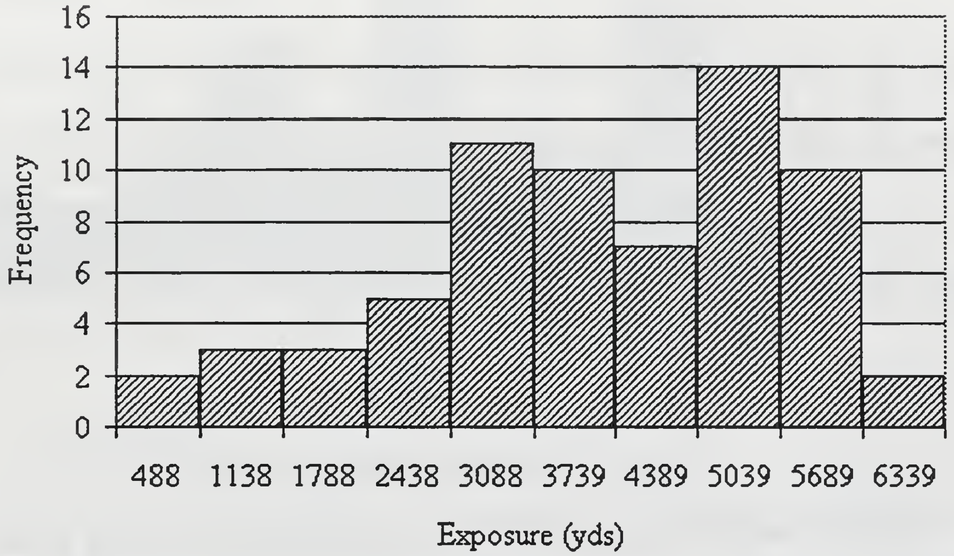

Figure 4.6 Frequency Histogram of Exposure.

The distribution of the Time is shown in Figure 4.7. As can be seen, the frequency distribution of time is fairly evenly distributed, with approximately equal median and mean, indicating a full spread of engagement times among subjects and no significant biasing toward either a long or short engagement duration. A Kolmorgorov-Smirnov Goodness-of-fit (KS) test for uniformity fails to reject a uniform distribution with a p-value of 0.76. This result is surprising considering the instruction set given to the participants. It was thought that the subjects as a whole would have shot much more quickly. Coupled with the earlier lack of reliance on the torpedo's capabilities, as shown in the distribution of the weapon to target CPA parameters, the subjects seem to show a bias toward a more conservative approach methodology.

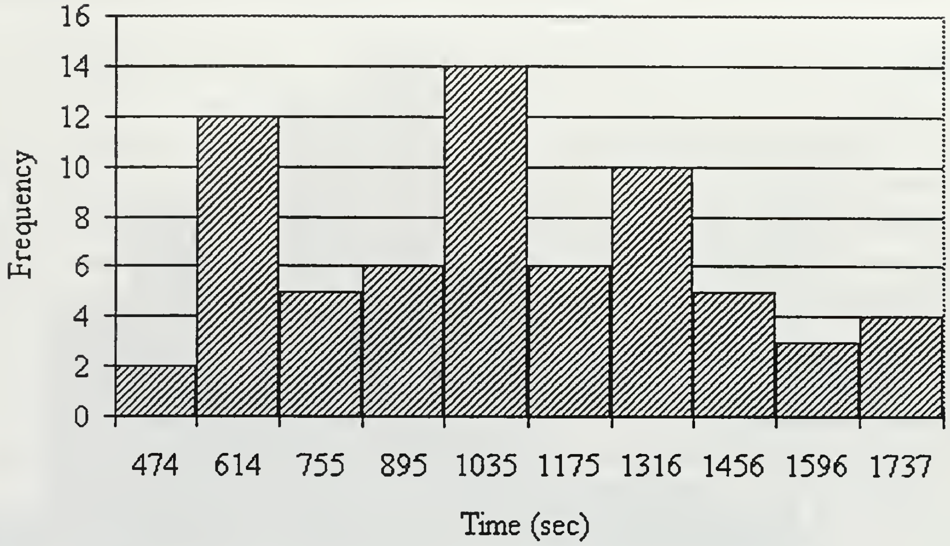

Figure 4.7 Frequency Histogram of Time.

An examination of the probability cross-tabulations between the binary variables of TIME, EXPOSURE, and HIT, as shown in Table 4.2, reveals noticeable dependence. A χ^2 test for independence indicates that the three variables are indeed dependant (χ^2_4=10.63, p-value=.03). Therefore, subjects that succeed in one measure are more likely to succeed in another and visa versa.

HIT=0			**HIT=1**		
TIME\EXPOSURE	**0**	**1**	**TIME\EXPOSURE**	**0**	**1**
0	0.00	0.00	**0**	0.05	0.05
1	0.02	0.02	**1**	0.06	0.80

Table 4.2 HIT vs. EXPOSURE vs. TIME Probability Cross-Tabulations.

As outlined earlier, the three binary factors of HIT, EXPOSURE, and TIME, are multiplied to determine if the engagement is a success. Recall that if all three factors are classified with a 1, the engagement is a success and a 1 is recorded for the variable SF. If any are classified with a 0, then the engagement as a whole is a failure and a 0 is recorded

for SF. Using that criteria, the subject population, as a group, achieved a 77% success rate (n = 50) and a 23% failure rate (n = 15).

C. SUBJECT MODELS

The next step is to determine which models, if any, can be used to adequately describe subject performance. Due to the availability of both continuous and binary response variables (CE and SF), that capture two different aspects of subject performance, and the six demographical predictor variables, two different models are developed.

1. CE Models

First, plots of CE and Time vs. all seven (POS, TYPE, LOC, EDU, ROT, SCEN, and SF) demographic variables are examined for differences in the mean value of CE and Time. These are shown in Figures 4.8 and 4.9. As can be seen, the differences in mean Time are considerably less than the differences in mean CE. This indicates that except for the variable SF, there appears to be no significant interaction between Time and the six remaining subject demographic variables. Alternatively, there are noticeable interactions between CE and the demographic variables of SF, LOC, ROT, and TYPE.

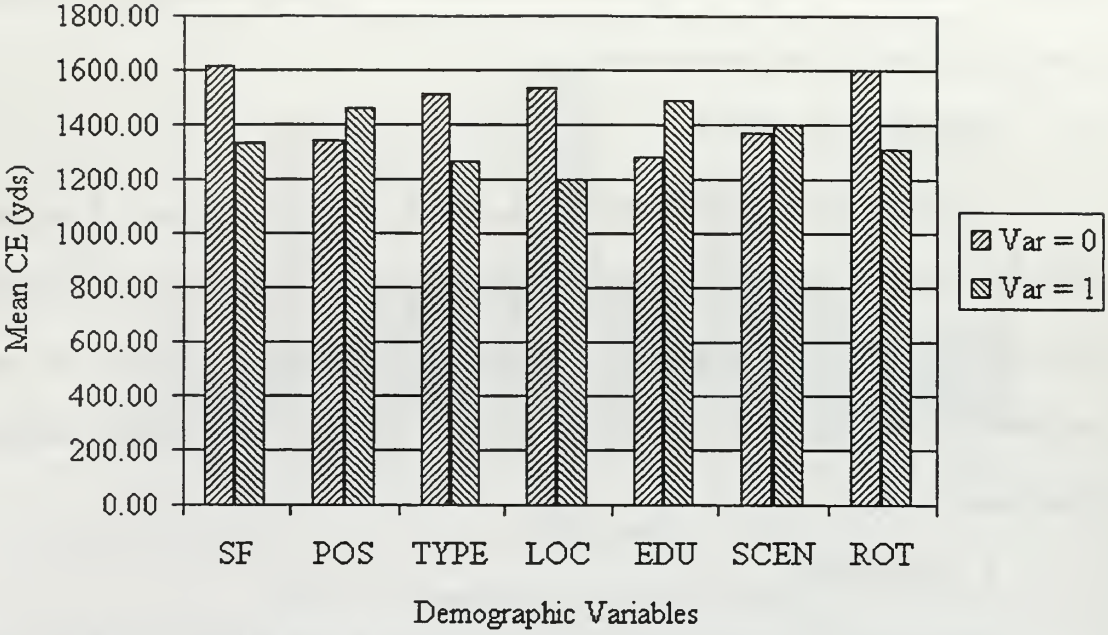

Figure 4.8 Mean CE (yds) by Demographic Variables.

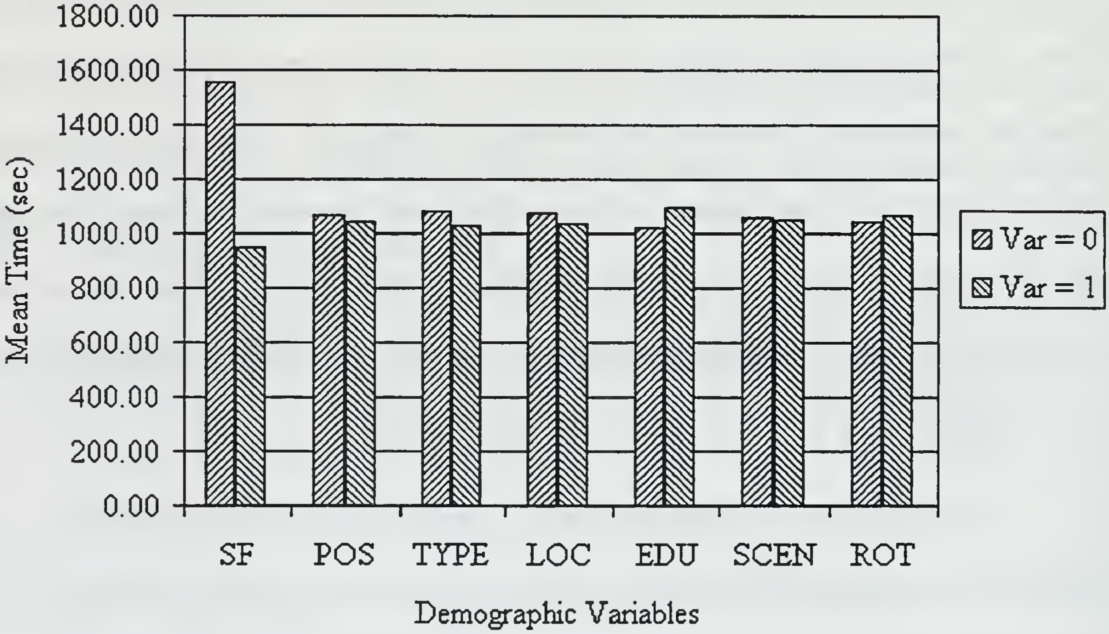

Figure 4.9 Mean Time (sec) by Demographic Variables.

A Welsh's modified two sample T-test is run on the differences in mean CE and mean Time with respect to each of the seven demographic variables to determine if the

results were indeed significant[1]. As was the postulated earlier, the factors of SF, TYPE, LOC, EDU and ROT show significant effects for CE, while only SF shows significant effects for Time. We note that with the number of two sample tests performed, the p-value becomes a descriptive statistic. Nevertheless, the p-values still indicate that there is "strong" evidence that there is a difference in the expected MOE's between the two groups. However, the exact level of significance of the test is somewhat more difficult to quantify. The outcome in the form of the mean values and p-values is shown in Table 4.3.

Response	Variable	Variable=0	Variable=1	p-Value
Mean Time	**SF**	1557.91	947.46	<0.01
	POS	1066.03	1046.01	0.82
	TYPE	1084.55	1032.35	0.55
	LOC	1073.93	1038.69	0.69
	EDU	1023.36	1093.53	0.42
	SCEN	1061.39	1055.12	0.94
	ROT	1045.32	1063.00	0.86
Mean CE	**SF**	1617.03	1334.33	0.03
	POS	1341.08	1458.96	0.62
	TYPE	1508.00	1263.46	0.02
	LOC	1529.99	1201.67	0.01
	EDU	1280.45	1491.01	0.06
	SCEN	1371.44	1401.86	0.85
	ROT	1597.68	1312.19	0.02

Table 4.3 Descriptive P-values for Differences in Mean CE and Mean Time.

Next, speed (Time) vs. accuracy (CE) is fit as a function of the seven demographic variables. This is accomplished by linearly regressing CE on Time with each of the seven demographic variables considered separately. In each case, the interaction of the demographic variables with the factor Time is also included. Figures 4.10 through 4.16 show the results of these multiple regressions. As can be seen, the variables of SF ($F_{2,63}$=4.03, p-value<.01), LOC ($F_{2,63}$=3.09, p-value<.01), TYPE

[1] For the purposes of this research, significance is defined as p-value<=.10.

($F_{2,63}$=3.06, p-value<.01), EDU ($F_{2,63}$=2.76, p-value=.01) and ROT ($F_{2,63}$=2.42, p-value=.01) all show significant effects. The variables of SCEN ($F_{2,63}$=.37, p-value=.34) and POS ($F_{2,63}$=.35, p-value=.35) were negligible. These first results, particularly those from the POS regression, contradicts the expected notion of the distinction between experts and novices, and raises the issue of a possible reevaluation in the use of military rank as the primary designator of expert and novice. In addition, the significance of the ROT factor indicates that AO skills are fragile in that those subjects that utilize their skills on a frequent basis maintain a better mastery of the subtleties of the task, while those that are otherwise engaged experience a degradation in their abilities.

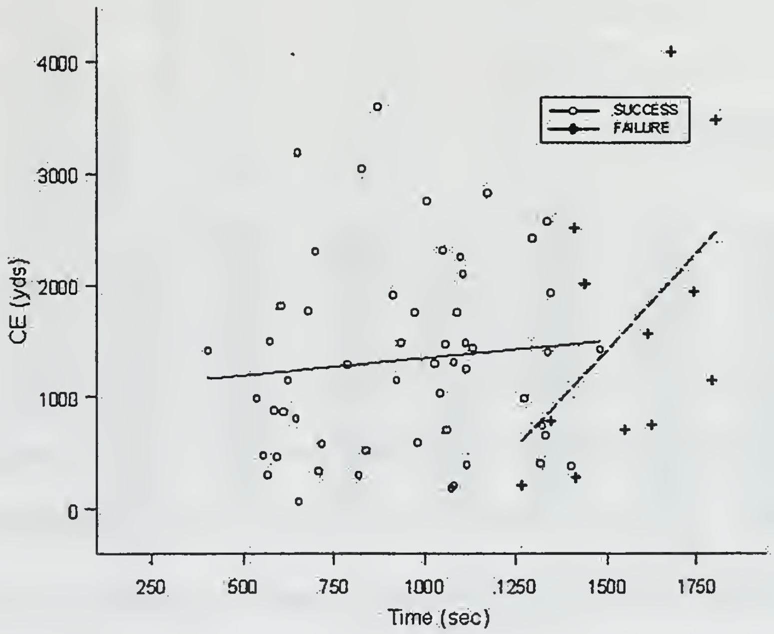

Figure 4.10 Speed (Time) vs. Accuracy (CE) Regression Conditioned on SF.

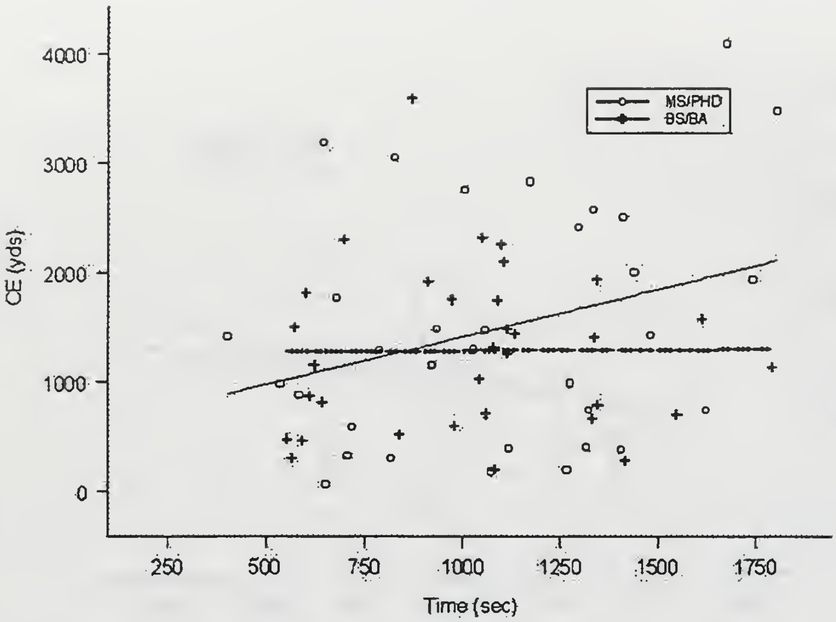

Figure 4.11 Speed (Time) vs. Accuracy (CE) Regression Conditioned on EDU.

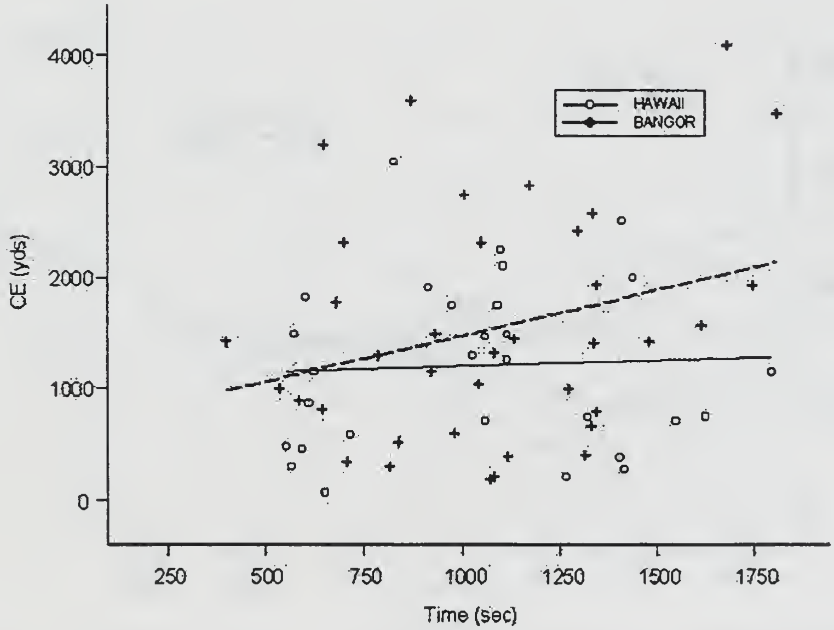

Figure 4.12 Speed (Time) vs. Accuracy (CE) Regression Conditioned on LOC.

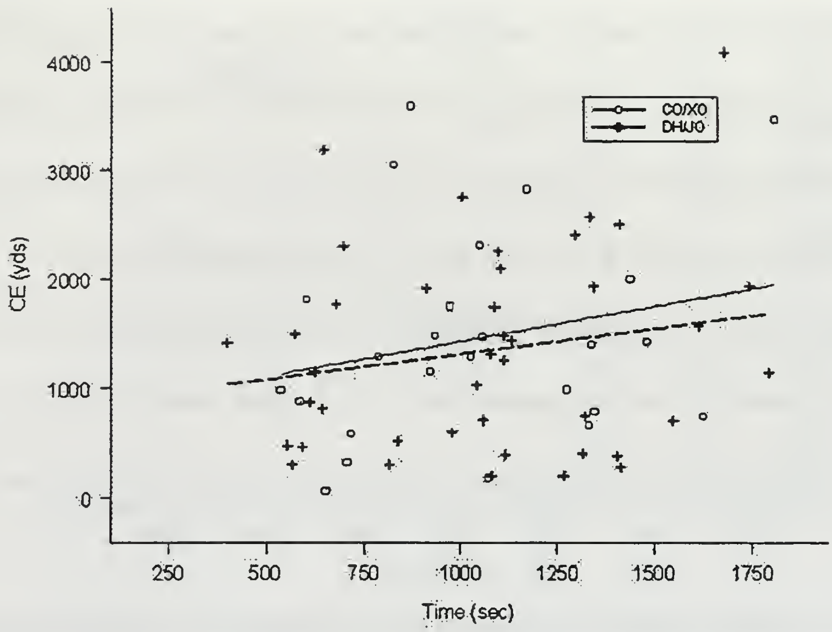

Figure 4.13 Speed (Time) vs. Accuracy (CE) Regression Conditioned on POS.

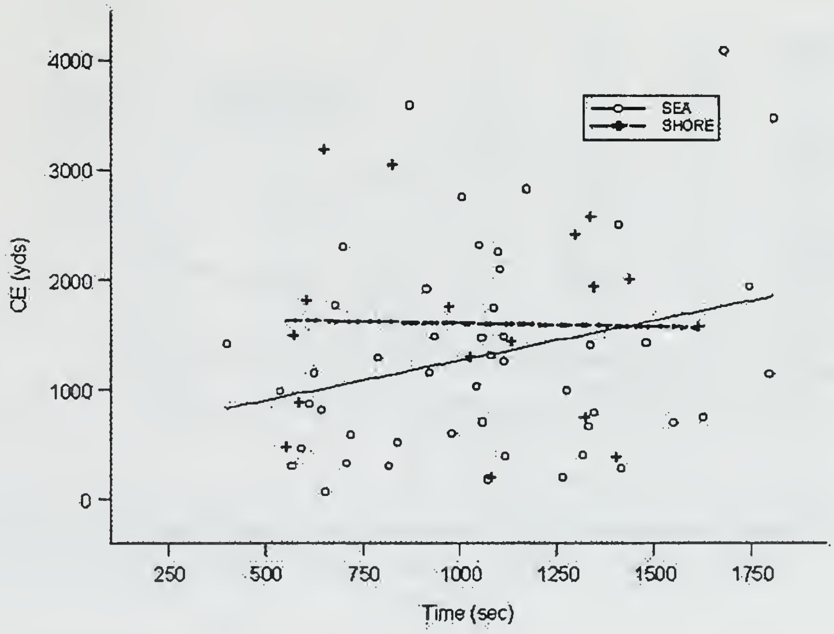

Figure 4.14 Speed (Time) vs. Accuracy (CE) Regression Conditioned on ROT.

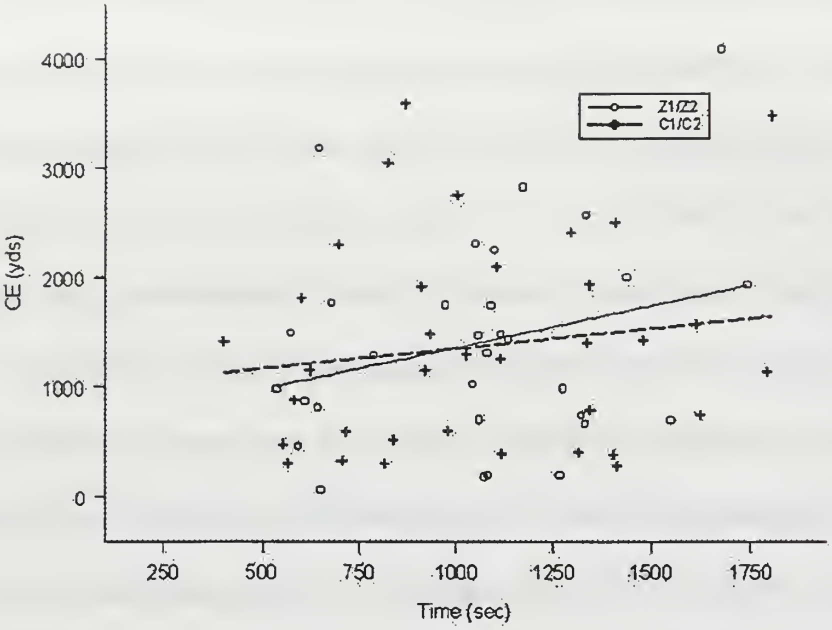

Figure 4.15 Speed (Time) vs. Accuracy (CE) Regression Conditioned on SCEN.

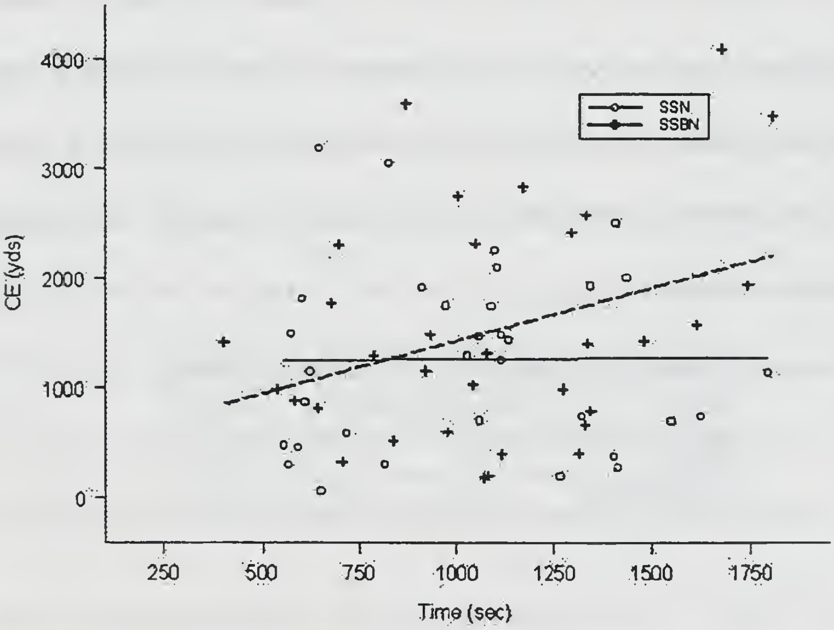

Figure 4.16 Speed (Time) vs. Accuracy (CE) Regression Conditioned on TYPE.

Additionally, when the sign of the slope of the regression line was examined in under all possible combinations of subjects (2^7), only one combination (POS=0, LOC=1, TYPE=1, EDU=1, ROT=1; n=6) showed a negative value. A binomial sign test applied to the null hypothesis that the probability of a negative slope is 1/2 against the alternative hypothesis that the probability is not 1/2, finds significance in that in no case does a longer engagement lead to a more accurate solution. Therefore, it appears that an AO's best solution is the first, and any further refinement may be of little value.

Finally, a full model fitting CE vs. all seven demographical variables and their interaction with Time is examined. Using Mallow's Cp, a stepwise linear regression is conducted. The variables of SF, Time, and SF x Time comprise the best-fit model with a multiple correlation coefficient of 0.31. Table 4.4 shows the estimated coefficients of the predictor variables and the associated p-values remaining in the "best fit" model. These results loosely correspond with the earlier results obtained from the examination of mean CE and the speed vs. accuracy trials. Examination of the full model reveals that the highest correlation possible between CE and the fitted CE occurs with value of 0.45. Therefore, with the three factors in the best-fit model, 69 percent of the total possible model correlation is attained.

Variable	**Coefficient**	**SE**	**p-Value**
SF	1036.86	451.11	0.02
Time	1.06	0.17	<0.01
SF x Time	-0.75	0.49	0.10

Table 4.4 "Best Fit" Linear Regression Model Coefficients and p-Values.

2. SF Models

The second model examined is a logistic model with factor SF as the binary response and the six subject demographic variables (EDU, LOC, POS, ROT, SCEN, and TYPE) as the binary predictors. Construction of the model follows two separate methodologies.

First, the model is fit with the full data set. This allows for the estimation of the expected probability of success for each subject based on the particular combination of predictor variables. Since these probabilities range from 0 to 1 and the actual response variable was binary, all fitted probabilities greater than 0.50 are assigned a value of 1 and all those probabilities less than 0.50 are assigned a value of 0. The model is tested by examining the correlation coefficient between the actual and predicted success vectors. As shown in Table 4.5, the factors of TYPE, LOC, and POS have the greatest impact with a model correlation of 0.81.

Second, the data was randomly split into two separate sets each of equal size. The model was fit to half of the data set and then applied to the other half in the prediction of success. This was repeated 10 times for standardization. As shown in Table 4.5, the average correlation between actual and predicted success for the 10 repetitions is .76. As with the full model, the factors of TYPE, LOC and POS have the greatest influence. In both the full and ten random models, errors in the prediction of success are predominately due to an overestimation of a subjects abilities rather than underestimation.

VARIABLE	BETA	FULL MODEL	10 RANDOM MODELS
POS	$\beta 1$	0.87	1.32
TYPE	$\beta 2$	5.71	5.13
LOC	$\beta 3$	-5.57	-4.91
EDU	$\beta 4$	-0.04	0.06
SCEN	$\beta 5$	0.72	0.81
ROT	$\beta 6$	0.68	0.71
Correlation coefficient	r	0.81	0.76

Table 4.5 Regression and Correlation Coefficients for the Full and Random SF Models.

In an attempt to visualize the results of the logistic regression model of subject performance, CART techniques (SPLUS, 1997) are utilized. Figure 4.17 shows the classification tree for the subject performance model. The estimated probability of success (Ps) for each leaf is at the terminal node. Due to the nature of the data, i.e. binary values independent of each other, the CART tree is ideal for quickly identifying a subject by their demographic variables and their associated probability of success. For example, for an AO from Bangor (LOC=0), with a BS degree (EDU=0), attempting scenarios C1/C2 (SCEN=0), we follow the tree down and to the left to get an estimated probability of success of 0.75. As with earlier models, the factors of LOC, EDU, and ROT are significant while yet again, the factor of POS is negligible. The misclassification rate for the CART model was .22. When compared to the correlation coefficients arrived at with the logistical model (r=0.81, r=0.76), we find that the CART analysis arrives at similar conclusions.

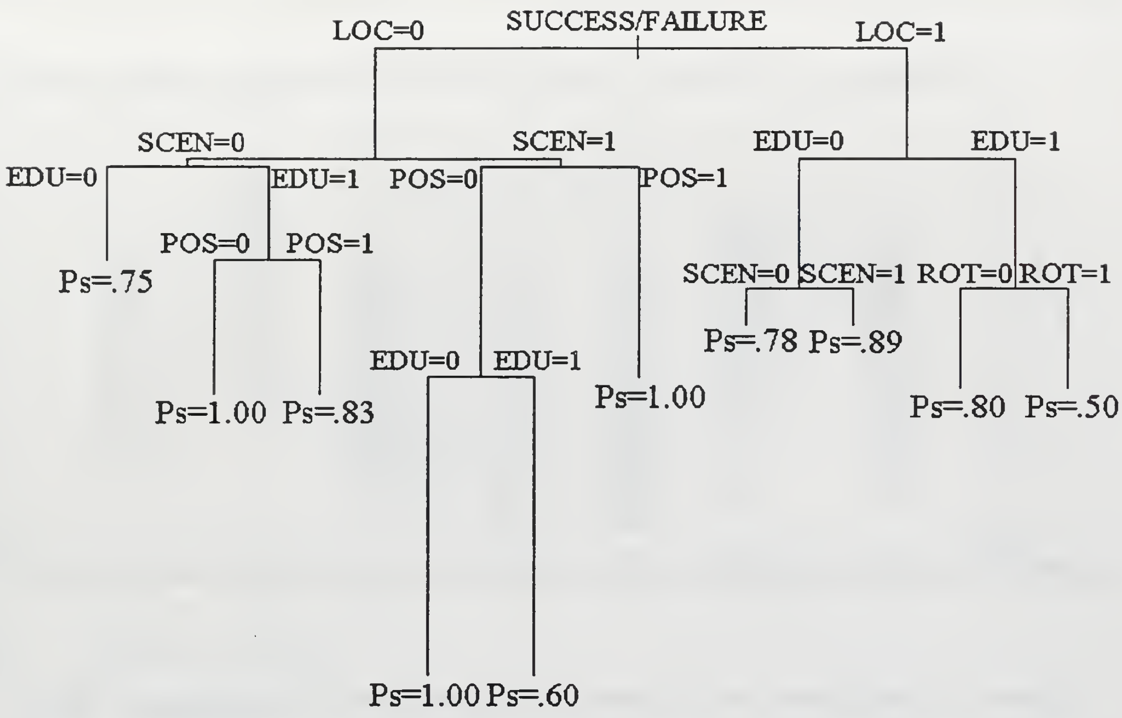

Figure 4.17 CART Estimated Probability of AO Success based on Demographic Variables.

The second approach examines the relationships between the 92 dependent variables of display usage and solution generation, and the 7 (SF, POS, LOC, EDU, ROT, TYPE, and SCEN) independent demographic variables. Because the measurement scales of the dependent variables differ considerably, each dependent variable is standardized prior to analysis. The distributional differences of the 92 dependent variables are examined in two ways. First, to see if the expected value of the dependent variables differ with the level of the independent binary demographic variables, two sample T-tests are run on the 92 dependent variables as a function of the independent variables. The outcome of this is a 7 x 92 matrix of p-values indicating differences in the mean value of each of the 92 variables as a function of the seven demographic variables. Box-plots of the 92 p-values for each of the demographic variables are shown in Figure 4.18.

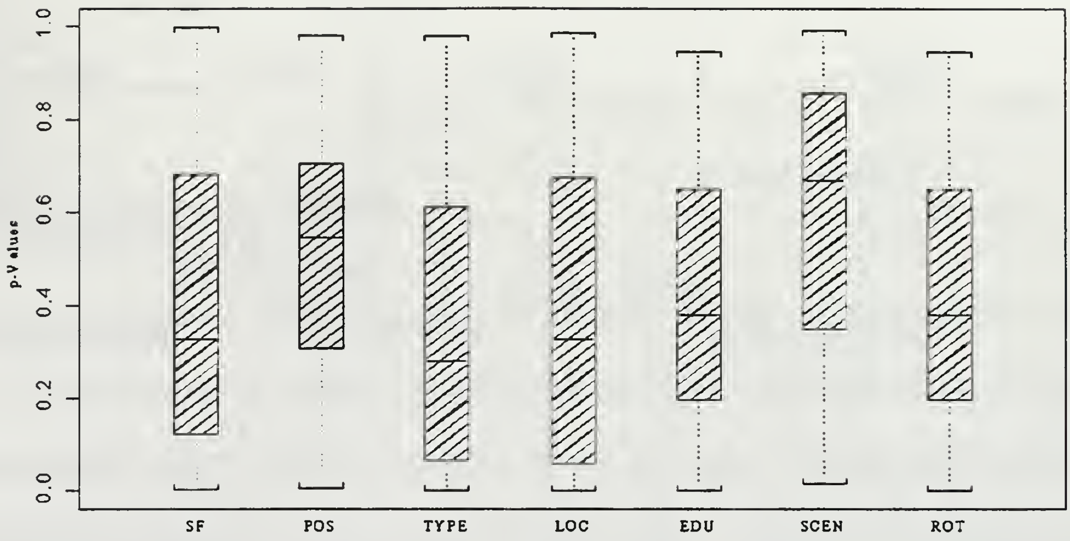

Figure 4.18 Boxplots of the 92 Display Usage and Solution Generation p-Values.

However, in testing 644 (7x92) hypothesis, both random statistical noise and actual statistical differences are expected to be present. If there is no difference in say LOC, then we would expect the 92 p-values for LOC to be uniformly distributed between zero and one. By examining Figure 4.18 it appears that the p-values for all demographic variables, with the exception of POS and SCEN, are less than expected. To confirm this, for each of the independent variables, a Kolmorgorov-Smirnov Goodness-of-Fit test for uniformity is applied to the 92 p-values to test to see if any significance that was found was due to actual differences in the independent variables, and not due to random statistical noise. Secondly, to verify these results, a χ^2 test was run on the actual distributional relationships among the independent variables. The results are shown in Table 4.6. As can be seen the variables of SF, LOC, TYPE, and SCEN were significant at the α=.05 level and the variables of EDU and ROT was significant at the α=.1 level.

Surprisingly, the variable of POS was not a distinguishing trait in either of the two tests. This gives added weight to the earlier conclusions of the linear regressions.

VARIABLE	p-Value	
	KS	χ^2
SF	0.01	0.04
EDU	0.06	0.09
LOC	0.01	0.01
POS	0.74	0.53
ROT	.05	0.08
SCEN	0.01	0.01
TYPE	<0.01	0.01

Table 4.6 KS and χ^2 p-Values for Display Usage and Solution Generation Differences.

D. DISPLAY DESIGN

1. Data Input

The basic foundation of human interface display design is to model the display after the expert, or "expected", operators (Bailey, 1980; Wickens, 1992). In this experiment, however, the designation of "expert" operator has shown a lack of significant performance distinction. Therefore, the "successful" operator is used instead. This way, patterns of behavior that cut across the demographic differences of AO's are exploited for use in developing the underlying principles for CWS design parameters.

A single step link analysis is performed upon the patterns of display usage and solution generation of the successful operators. The patterns of display usage are categorized as belonging to a 10 x 10 matrix. The number of transitions from each one of the 10 displays to another is counted and then standardized into subject specific frequencies with the constraint that all of the 100 frequencies add to one. The 10 x 10 matrix is then collapsed to a 4 x 4 matrix according to the coding scheme as follows:

SONAR (SAPBB, TAPBB, TAPNB), DERIVED (TB, TF, GEO, LOS), ENVIRON (OSC, SVP), and SOLN (TMA). The result of the link analysis is shown in Figure 4.19.

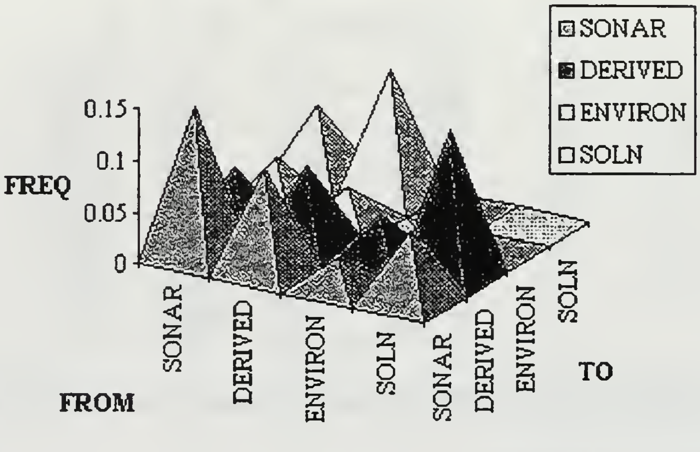

Figure 4.19 Successful AO Display Usage Link Analysis.

As can be seen the successful operator utilizes a unique distribution of display usage in the course of arriving at a solution. The three links of SONAR-SONAR, SOLN-DERIVED, and DERIVED-SOLN account for more than 50% of the total links.

A single step link analysis is also performed upon the patterns of solution generation of the successful operators. The patterns of solution generation are categorized as belonging to a 4 x 4 matrix with the elements of target Bearing, Range, Course, and Speed, as the anchor points. The number of transitions from each one of the 4 elements to another were counted and then standardized into subject specific frequencies with the constraint that all of the 16 frequencies add to one. The result of the link analysis is shown in Figure 4.20. As can be seen, there are no obvious biases or patterns in the progression of links. Hence, the absence of a distribution is, in and of itself, important.

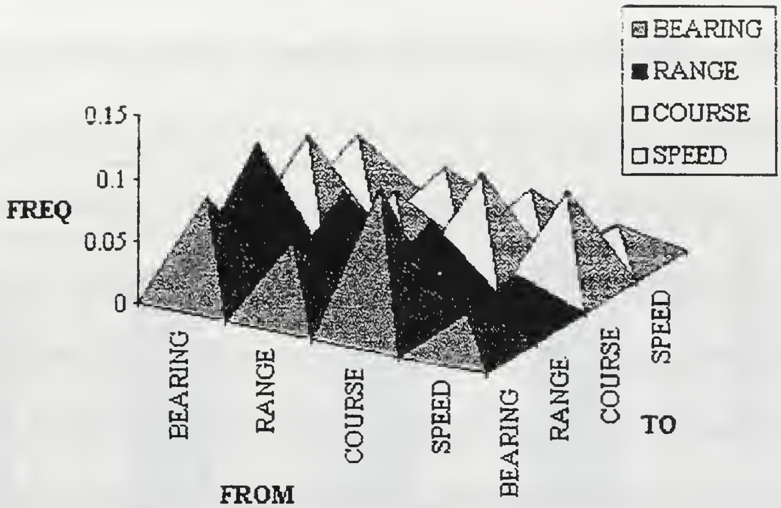

Figure 4.20 Successful AO Solution Generation Link Analysis.

Close examination of the procession of both link analysis frequency distributions show that in both cases, successful subjects follow the standard contact-reporting liturgy. That is, from Bearing to Range to Course to Speed. Deviation from this progression appears to be detrimental to the outcome of the engagement. This deviation could be responsible for actually inhibiting the correct decision-making and schema forming process.

2. Survey Input

Subject ratings of current CCS display effectiveness and usefulness are measured with both a five and a ten-point ordinal ranking scheme. The mean rating of each display is compared against the others in the determination of the relative position of each display. Again, the displays are recoded using the same methodology as in the link analysis. The results are shown in Figure 4.21 and 4.22. In the measurement of utility, the ENVIRON displays were at the top while the SOLN displays were at the bottom. In the measurement of effectiveness, the SONAR displays were at the top while the DERIVED displays were at the bottom. These results indicate that certain CCS displays

are actually inhibiting the users SA by failing to provide the required information in the proper format. This also could inhibit the proper development of schema's.

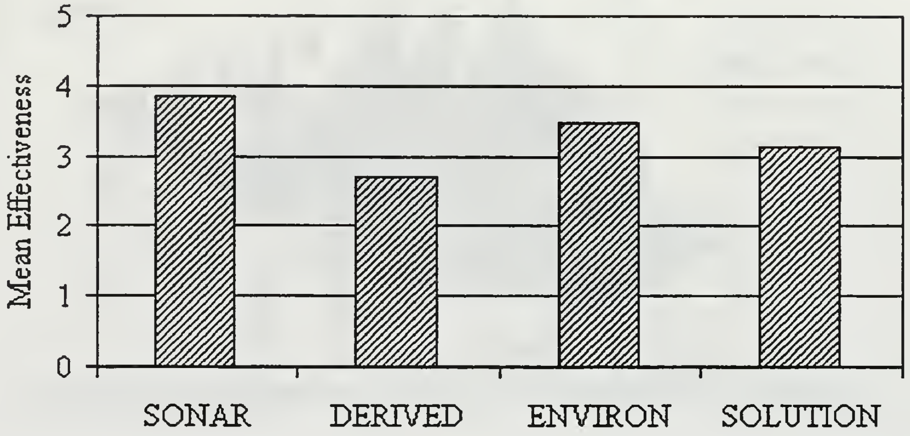

Figure 4.21 Subject Response for the Mean Effectiveness of CCS Displays.

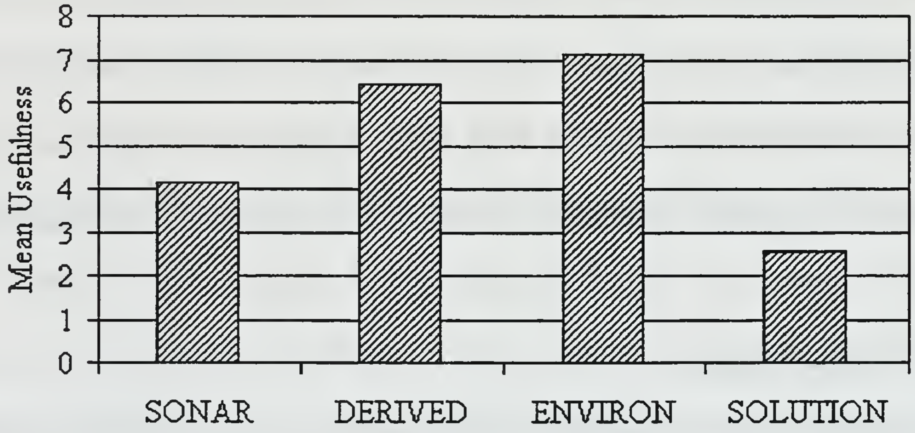

Figure 4.22 Subject Response for the Mean Usefulness of CCS Displays.

Subject response to the open-ended question regarding desires for the next generation of CWS was mixed. Approximately 30% of the subjects did not complete the question in any form. Of those that did, only 10% provided a written response. Most subjects, 60%, preferred to interact with the interviewer in a "brainstorming" session. The sessions typically lasted 20 minutes with one lasting as long as 2 hours. Their responses were manually recorded and then analyzed for salient features. A salient

feature is defined as a point, or issue, of focused interest by the subject for an attribute, or ability, that is desired of the CWS. Additionally, an in-situ drawing was kept by the interviewer and presented to the subject at the end of their input in an attempt to elicit further input and/or criticism. This drawing was updated after each subject's input and evolved in response to the subject pool desires for the CWS. A frequency analysis of the subject generated salient feature is shown in Table 4.7. As can be seen the top five attributes were the availability of history, multiple tasking capabilities, information standardization, alternative evaluation, and single point origination of information.

FEATURE	FREQUENCY
Availability of history	83
Multiple tasking capabilities	75
Information standardization	64
Alternative evaluation	63
Single point origination of information	59
User defined modes	54
User defined layout	50
Increased use of computer algorithms	50
Increased use of cots	45
Electronic publications	40

Table 4.7 Frequency of Salient Features Generated During Subject Feedback.

The top five features desired by the subjects indicate a desire for the CWS to be fully integrated with the current support systems internal to the submarine as well as providing for relief from the current memory intensive processes now required of AO's. In addition, most subjects made the comment that it would be advantageous and worth the expenditure required to have displays available for use that were based on technology less than 10 years old.

V. DISCUSSION AND CONCLUSIONS

This thesis had three primary objectives. The first objective was to explore possible relationships between both subject demographic differences and CCS employment strategies in the prediction of a successful engagement. The second objective was to provide data in the development of a notional "AO friendly" CWS interface. It is postulated that this interface will allow the AO to more accurately evaluate relevant tactical information with less effort through the use of more appropriate information presentation and display formatting. Finally, the third objective was to provide for principles which could be applied in the areas of personnel selection, qualification, and training.

The areas of HIP, NDM, situational awareness, schema theory, expert vs. novice performance and the principles of display design were examined in detail. In particular, the military applications, past and present, of the six theories were discussed. As noted, most of the previous work has been used in pilot/aircraft interface analysis, and was not specific to submarine AO's. However, as in Hooper (1994), we postulate that the gap between the two is so slight as to infer parallel results.

A computer-based simulation was created and presented to approximately 10% of the active duty submarine AO's. The subjects were run though two of four pre-scripted initial contact scenarios in a modified Latin square design. Two objective and one subjective evaluations of performance were obtained. Solution accuracy at TOF and eventual weapon to target CPA were continuous objective measures, while the determination of a "successful" engagement was subjective. In addition, the subjects

participated in a design survey to facilitate feedback on not only the simulation presented to them, but also specific desires for the next generation of CWS.

An exploratory statistical analysis was performed on the subject-generated database with the goal of determining if subject demographic differences or CCS usage strategies are predictive of subject performance. Both logistic and linear regression techniques were applied to the measures of SA obtained for the subjects. In the prediction of a successful engagement, the factors of geographical location, ship type, and duty type were the three most important determinants. While these three attributes are not surprising when taken as a group, their order of relative importance and the absence of the distinction of Expert or Novice was not expected. This coupled, with an almost zero correlation between CE and number of years at sea, a synonym for expert designation, raises the question as to whether a good AO is “born or made”. Analysis of linear relationships between time of engagement vs. CE (Speed vs. Accuracy) reveals two important observations. First, the shorter the engagement, the more accurate the solution that is shot. And second, once again, expert vs. novice distinction is negligible, while geographical location, ship type, education, and duty type are clearly observable effects in terms of the MOE's utilized. It was then shown via application of Welsh’s modified two-sample T-test coupled with Goodness-of-fit tests that factors of SF, EDU, LOC, ROT, and TYPE do in fact demonstrate variance in the cognitive progression of links in both display usage and solution generation. This lack of a distinction between expert and novice operator conflicts with the results expected from the literature. Perhaps, the core distinction between experts and novices cannot be gleaned from something as simple as

rank. The effects of the demographic variables conclude that the distribution of AO skill is not evenly spread out across such factors as geographic location and ship type.

A single-step link analysis was examined on both display usage and solution generation. The question of selecting which subject distinctions to condition on was solved by only examining the differences between successful and unsuccessful subjects. The successful subjects were shown to follow standard submarine liturgy and submerged approach methodology (as explained in Chapter 4), while unsuccessful subjects were observed to be going about their approach in a seemingly ad hoc manner. This ad hoc manner, commonly referred to as “Easter-egging," exhibited no definable sequence or pattern of informational usage. This further reinforces the benefits of reliance on established methodologies and techniques. Rather than attempt to develop their own individual style, AO's should instead concentrate on techniques that have been proven to work. As the saying goes, "all you need is rhythm." Finally, results from the two link analyses were fused with both subject evaluations of the current CCS’s, and subject desire for attributes of the next generation of CCS in the construction of a preliminary CWS design. While the original mandate envisioned that subject input would only be made for the fire control module portion of the CWS, subject dissatisfaction with the current CCS’s and the strong desire for a revolutionary leap in CCS employment, significantly expanded the scope of subject input. The final product therefore, is touted to be an attempt to describe the initial design parameters for a complete CWS encompassing all aspects of AO employment.

A. NOTIONAL CWS DESIGN

To reiterate, a 3-pronged display design approach was utilized in the development of the principles for the CWS. This approach combined the subject survey evaluations of the effectiveness and usefulness of the current CCS displays, the link analysis extraction of the display usage and solution generation patterns of the "best" group of AO's as distinguished by the distributional and categorical relationships identified, and the top ten salient issues generated by subject. The principles and parameters developed are presented as a basis upon which future research can capitalize.

The physical layout of the CWS is founded on two, side by side, large (i.e. 19–23 inches) computer touch screens. Touch screens were selected for their ease of use and quick response capabilities. The left CWS display, shown in Figure 5.1, consists of four fixed modules with an optional fifth for submarines with strategic commitments. The GEO-PLOT and CRO modules share the same function as the modules of the same name in TADMUS. The O/S CONDITION module displays all actual and ordered kinematic parameters (course, speed, and depth) for own-ship. The SVP module is a graphical representation of the current ocean environment. Ship's depth would be displayed graphically within the appropriate current SVP. The optional module for the left CWS is an event timer for submarines with strategic commitments. This option was not desired by the non-strategic community but was deemed important by the strategic community. This timer would operate in the same manner as the response manager in TADMUS. The location and size of the modules was determined by examination of the data and survey results. The modules are arranged to facilitate increased situational awareness by allowing for a more natural information flow between the system and the operator. This

then allows for a reduction in the cognitive workload of secondary tasks that are currently inhibiting the AO from forming the necessary schema's. The now liberated cognitive resources can be applied back to the AO's primary task, i.e., approach and attack of the enemy.

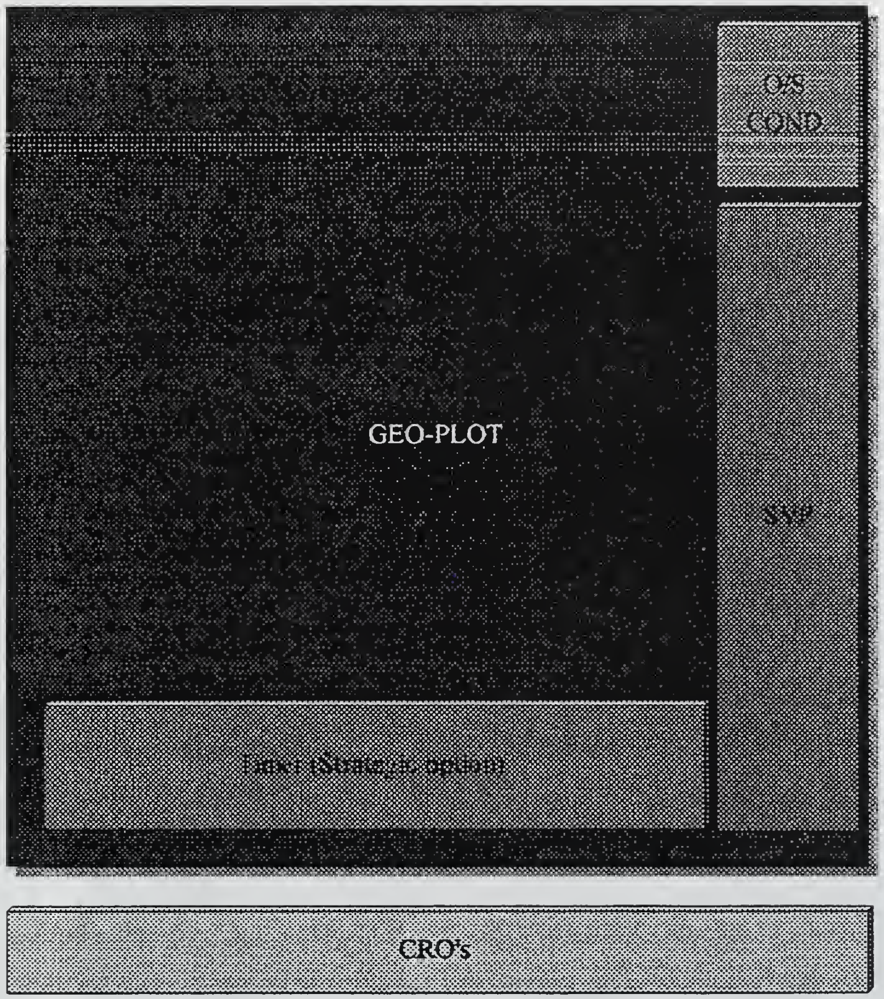

Figure 5.1 Left Side of Notional CWS Display.

While the left side of the CWS is rigid in structure, the right side is user determined. This flexible display concept is primarily an outgrowth of desire among AO's that the CWS be adaptable to a variety of situations and scenarios. This side of the CWS is split into three modules: an upper, a lower, and a series of selection buttons. The

right CWS is display is shown in Figure 5.2. The selection buttons determine which of the four upper sub-modules (SONAR, DAMAGE CONTROL, ENVIRONMENT, and ERP) and four lower sub-modules (FCS, RADIO, WEAPONS, and ENGINEERING) are displayed. The selection buttons operate such that only one of the upper sub-modules and one of the lower sub-modules can be displayed at any one time. The sub-modules are organized such that in most cases, no two upper or lower sub-modules will have to be displayed at the same time.

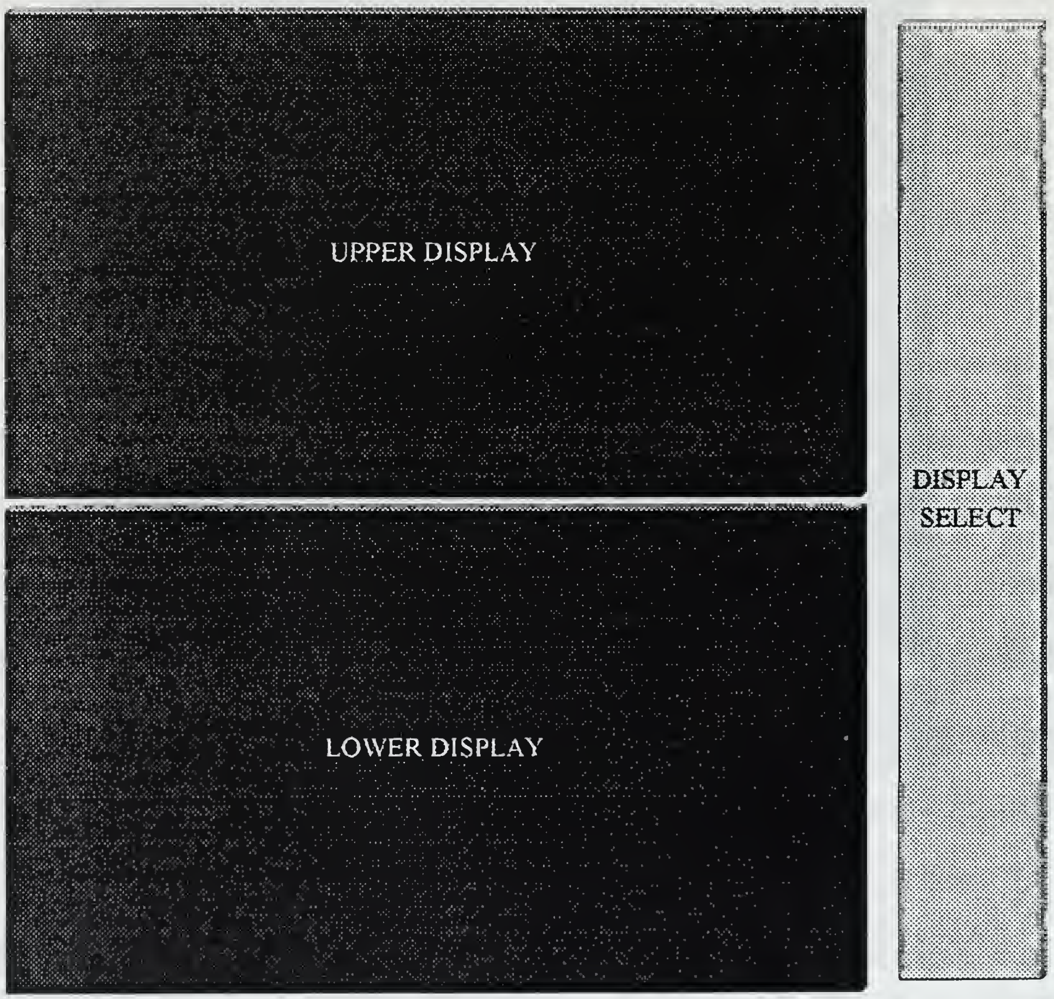

Figure 5.2 Right Side of Notional CWS Display.

The details of the sub-modules, with the exception of the fire control system sub-module (FCS), are not presented in this study due to space and time limitations. However, they were presented to the sponsor by separate correspondence. The FCS sub-module, shown in Figure 5.3, has four distinct areas each with a different purpose.

Figure 5.3 FCS Sub-Module of Notional CWS Display.

Area one is a standard contact report listing of all current information on the target of interest. The order is top to bottom, and is presented in numeric and bullet format to aid in rapid and detailed recall. Area 2, shown in Figure 5.4, itself consists of 4 areas. The solution area gives the current system solution to the target selected. The BRDD (Bearing Rate Difference Dots) and RRDD (Range Rate Difference Dots) areas are the same as the current iteration with the exception that they are standardized in their orientation. Currently, the time reference alternates between top-down and bottom-up. In the CWS, both would be top-down time referenced displays. The LOS area gives the standard 3-element representation of the current target geometry.

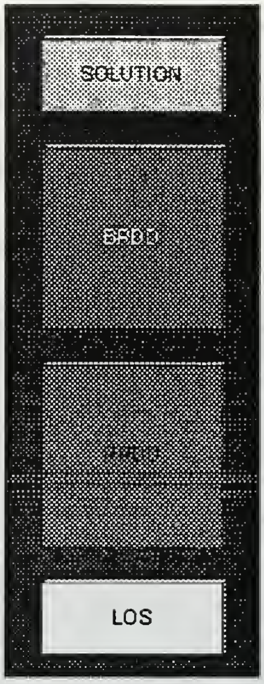

Figure 5.4 FCS Sub-Module – Area II.

Area three is the same as two, with the exception that area two is keyed to the current system solution and area three is keyed to the current trial solution. This structure allows for the viewing of both data representations in the same foveal area and therefore a reduction of the memory workload of the AO. This also speeds up the AO's decision-making process by reducing the waiting time required to make the mental comparisons between the current trial and system solutions. Area four is a window for viewing the FUSION plot. This plot, currently undergoing experimental evaluation, is a merging of the current TB, TF, GEO, and ENVIRONMENTAL plots. This plot allows for a "fusion" of all current tactical and organic information pertinent to the target selected. One additional attribute of this plot that was requested above all others was that it have a "time scaling" feature. In other words, the AO would have the ability to look back in history to allow for an EBR approach to the target's intentions. Such a display might look similar to Figure 5.5.

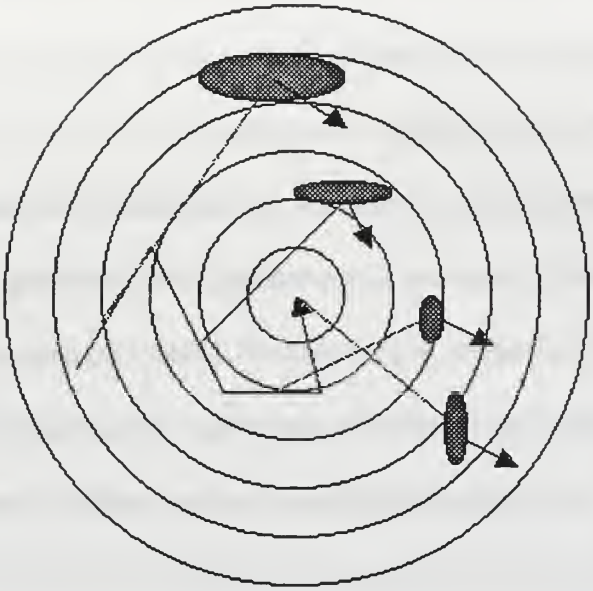

Figure 5.5 FCS Module – FUSION.

While the CWS's primary purpose is to aid in the completion of the AO's task, the expanded role desired by the subjects raises issues concerning its physical placement. The original CWS was envisioned to only be available in the submarine control room, however, with the added capabilities, it should be placed at several strategic locations. In particular, repeaters in the CO/XO stateroom and the officer wardroom would add in the process of maintaining situational awareness of the tactical and strategic situation by the submarine crew.

This notional CWS design should result in the following: First, significantly reduced processing time by presentation of tactical information in a natural and consistent manner. Second, an increased CCS functionality by allowing for a broader range of information to be available to the AO. Third, an increased rate of user interaction by allowing the user to specify the type and time of information presentation. And fourth,

an increased user acceptance of the system due to the fact that it was the users that determined CWS's form and function.

B. LESSONS LEARNED

Three lessons learned during the course of this research are worthy of mention:

1. The use of a "poor man's eye-tracker", while solving many of the difficulties in the data collection phase, was a point of serious consternation. Subject dissatisfaction was very pronounced and several subjects were outwardly hostile. The use of a head-mounted eye-tracker, while expensive, would be a better solution.

2. The simulation employed was limited in scope and fidelity by certain software design issues and constraints. Full employment of available hardware capabilities to ensure maximum realism and usefulness must be a priority before further fleet evaluation.

3. Analysis of the data generated indicates several areas meriting serious inquiry. Chief among them is the reevaluation of Expert/Novice designation. Issues concerning relevant display design issues need to be examined early in the procurement process in order to achieve maximum benefit.

C. RECOMMENDATIONS FOR FURTHER RESEARCH

Project NEMO shows great promise for Submarine commanders at sea operating in the high-stress, contact dense and politically ambiguous environments that the future surely promises. However, five further research issues merit consideration:

1. <u>Use of the database for further analysis.</u> Only a few data analysis avenues and hypotheses were examined in this thesis. Future work by NUWC, working in

conjunction with staff and students at NPS, should continue to explore the wealth of data collected during the course of this experiment. In addition, several areas were not explored due to the limitations of subject pool size, composition, and statistical significance. Continued data collection, perhaps from East Coast based submarine AO's, would provide the necessary database to alleviate this.

2. Continued CWS development. NUWC and ONR should seriously consider the principles developed for the preliminary CWS design proposed for further evaluation and possible implementation in tools such as Micro-SAINT (Wickens, 1992), with the eventual goal of formal presentation to the NSSN program office. This preliminary design, constructed for the first time by actual operators, should result in improved AO situational awareness, increased tactical proficiency, and greater overall operator satisfaction.

3. Cognitive modeling of novice system users. As stated earlier, the time constraints imposed by rapidly unfolding scenarios will surely be measured in minutes, possibly seconds, rather than hours or days. The systems must be able to be used effectively by the all levels of operators, since it is the Junior Officer who most likely will have the watch when hostilities commence. This would entail a reevaluation of the system from the "novice" point of view in order to facilitate maximum throughput of key tactical information. A mode command or toggle device installed into the system could be used to shift between levels of user skill.

4. Use of NEMO for Command Level training. The nature of command in a submarine control room is that the users operate in a windowless environment devoid of external stimuli or reference to the outside world. This environment

can be replicated quite easily via simulators. The simulators, based at major shore installations as separate entities or onboard the units themselves in the form of "canned training scenarios", would provide for the proper training of current and future commanders. The simulators could also provide some sort of diagnostic decision making performance measures that could be compiled automatically to indicate the skill of the user.

5. Use of NEMO for Command selection. Selection for command at sea, while monumental for the selectee, is at best a vague and uncertain process for selection boards. Frequently board members have little or no personnel experience or knowledge of the selectee and so they base their decision on paper reports, second-hand recommendations, and "sea stories." The CWS developed by Project NEMO could be used to supplement the board's decision by testing the potential commander's innate decision making process. That process could then be categorized to see if the selectee possesses the correct cognitive processes required of "successful" commanders. The selectee would be run through a scenario specifically crafted by the board and his, or her, outcome would aid in the determination of adequacy for command. Alternatively, since cognitive abilities are for the most part "born" and not made, the systems could be used for program entrance selection across the entire range of warfighter roles.

In conclusion, this thesis has provided insight into the cognitive processes of the AO. The proposed CWS, in addition to assisting the AO during tactical engagements, has applications in the selection, initial and continuing training, and performance evaluation of the AO. It is hoped that issues raised and conclusions drawn in the course

of this experiment will stimulate further research in the application of human factors principles to modern submarine design.

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APPENDIX A: TADMUS

TADMUS[1], which is currently in its second iteration of development, is entering the human factors test and evaluation phase. The program managers, after a full testing of the first iteration, significantly changed the layout, design, and cognitive models that drive TADMUS. Figure A1.1 shows the current screen layout of TADMUS. TADMUS consists six distinct modules each with a specific purpose: Geo-Plot, Multi-CRO Access Panel, Track Profile, Response Manager, Track Summary, and Basis for Assessment.

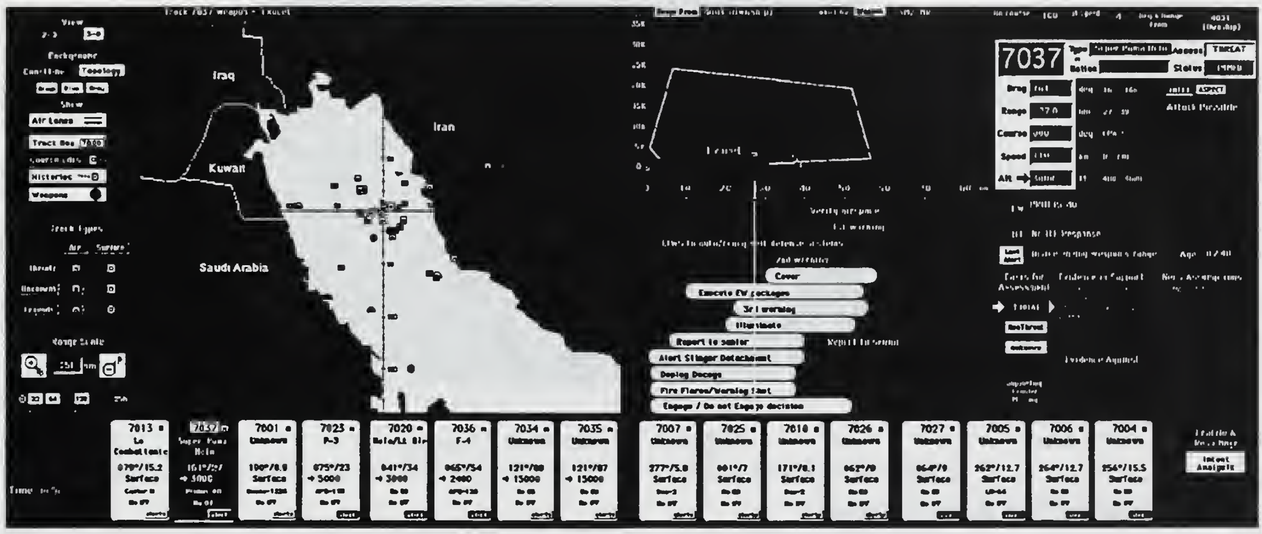

Fig A1.1 TADMUS Display.

Geo-Plot

The Geo-Plot module is the primary display for the command team (see Figure A1.2). It uses standard Naval Tactical Data Exchange (NTDS) color symbology as well as system track numbers to code all air, surface, and subsurface elements in the battlespace. The map can be expanded or enhanced to show any level of clarity available

[1] The following discussion has been excerpted from Dr. Hutchins writings on TADMUS in 1995/1996.
Hutchins, S.G. (1996). Principles for Intelligent Decision Aiding. (SPAWAR TM 1718). DON: Coronado, CA.
Hutchins,S.G. &Rummel, D.K (1995). A Decision Support System for Tactical Decision-making Under Stress. *Proceedings of the first International symposium on Command and Control Research and Technology*. Montery, CA.

in Joint Operational Tactical Exchange (JOTS). This ranges from general area maps to specific city street maps. In addition, users can overlay maps to increase detail or "de-saturate" them to reduce clutter. The Geo-Plot can also show weapons information such as range brackets, areas of uncertainty (AOU), and projected tracks (incoming and outgoing) to allow own ship to rapidly assess the criticality of a threat.

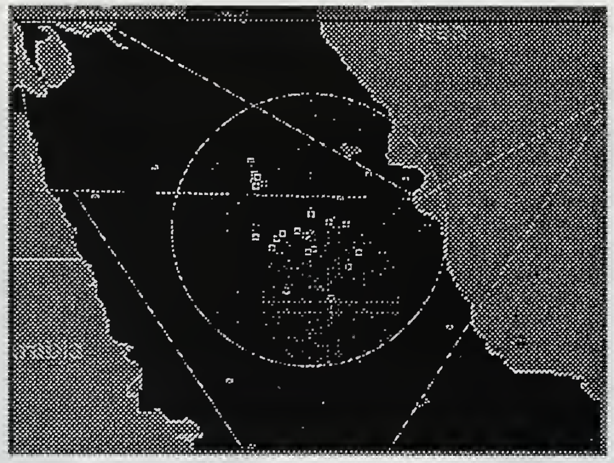

Fig A1.2 Geo-Plot Display.

Multi-CRO Access Panel

The Multiple-Character Read Out (CRO) Access Panel module displays all of the relevant information concerning target identification and kinematics (see Figure A1.3). In addition, it allows for the most critical tracks to be monitored without additional interaction from the user with the system. The buttons are all identical with priority assigned from left to right in order of decreasing importance. The CRO's are color coded to show threat status and "blink" when pertinent track information is available.

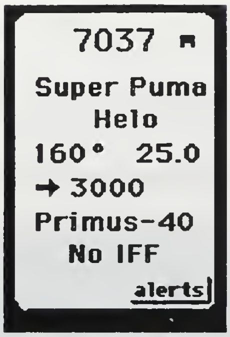

Fig A1.3 Multi-CRO Display.

Track Profile

The Track Profile module complements the Geo-Plot by displaying a side view of track altitude and range from own ship (see Figure A1.4). Information is available as to where the track is, what the track has been doing since tagging, when the track is within its presumed weapons range, and when own ship is within weapons range. The module also allows for own ship to evaluate multiple weapons type responses as well as projecting weapons effectiveness sphere's from other friendly assets in the battlespace. This feature will be critical for the notion of future "Joint Battle-Groups".

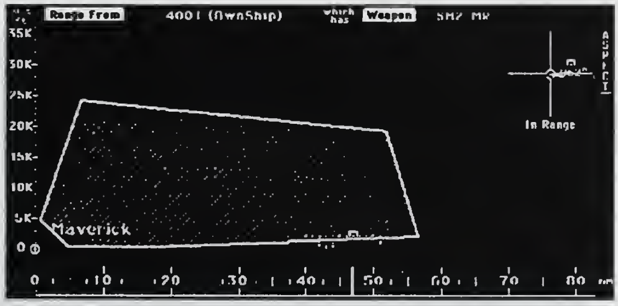

Fig A1.4 Track Profile Display.

Response Manager

The Response Manager module provides a Gantt chart type display showing a set of pre-planned actions as well as the optimal range for execution for the target of interest (see Figure A1.5). These pre-planned actions are intended to be based on the current

Order of Battle that the commander is operating under and can be updated as frequently as required.

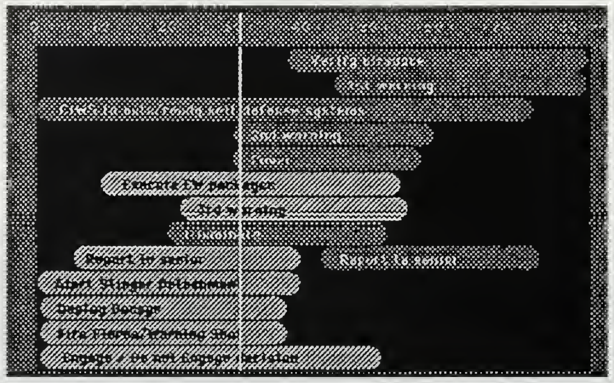

Fig A1.5 Response Manager Display.

Track Summary

The Track Summary module supplements the Multi-CRO panel by providing a detailed summary of all current and historical classification and kinematic data for the selected track (see Figure A1.6). It also provides for the display of ancillary data, such as intelligence, Electronic Warfare (EW), and Identification Friend or Foe (IFF).

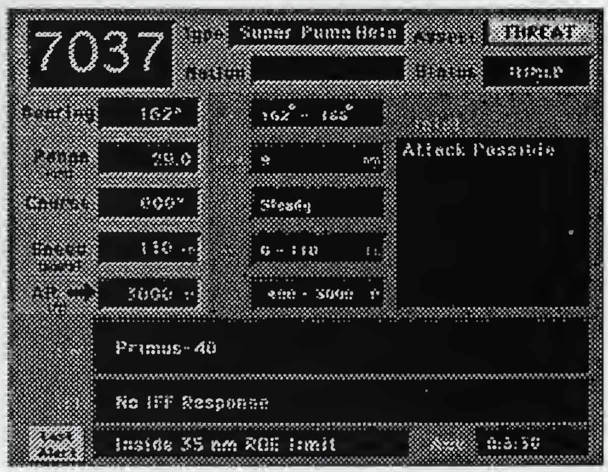

Fig A1.6 Track Summary Display.

Basis for Assessment

The Basis for Assessment module provides the command team with detailed lists of evidence for and against the current assessment of the selected track (see Figure A1.7). It also presents presumed, but yet unknown, information and implicit assumptions being made in accepting the classification of the contact as a potential non-threat, threat, or unknown.

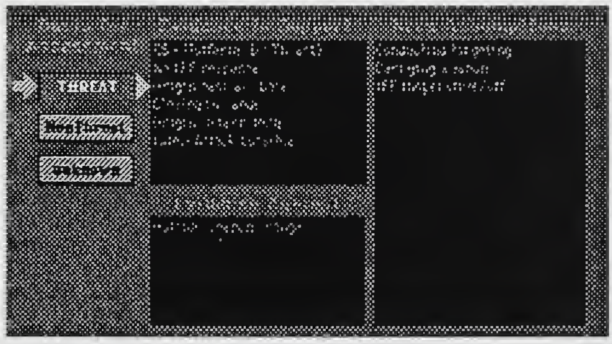

Fig A1.7 Basis for Assessment Display.

APPENDIX B: EXPERIMENTAL PROTOCOL AND INFORMED CONSENT

EXPERIMENTAL PROTOCOL

Ned Experimental Protocol (total duration ~2 – 3 hours)

Conventions

"⇒" is used before actions

Things in this format are to be read aloud verbatim.

Things in this format are to be read aloud verbatim and stressed

Things in this format are notes to the experimenter

Experiment Setup

⇒ **Put a fresh tape in the VCR and audio recorder, batteries in the audio recorder, and make sure the connections are all working**

⇒ **Be sure to disable any applications that run on a scheduled basis, such as Norton FileSaver, mail programs, etc., these will disrupt the timing in Ned.**

⇒ **Have the tic-tac-toe HyperCard stack up, running, and hidden.**

⇒ **Have the TTT video movie up, running, and hidden.**

⇒ **Have Ned (v1.5.5) up, running, and hidden.**

⇒ **Be sure to have the informed consent forms handy**

Experiment Briefing (5 - 10 min.)

The basic idea here is to give the subject a brief overview of the purpose of the study and what will be expected of them.

⇒ **Read:**

This is an unclassified system being used for basic research. This exercise will be audio/video recorded. Please keep all remarks unclassified.

Today I will ask you to participate in two scenarios using a simplified command workstation simulation. The purpose of this experiment is to gather data on how command might use information that is typically available in the Combat Control System. As you know, the new SSN that is being planned will have a dedicated command workstation (CWS) to support the Approach Officer. As this is a new console, there is little known about how such a workstation will be used. This experiment is one in a series of studies to predict the answer to that question. One thing we do know, gleaned from the experience of many submarine officers, is that the CWS will require different displays than those currently available on operator consoles. Your participation will help determine the content of those displays.

In this exercise, your role will be that of the AO.

Data collection in this experiment depends on making your information needs and usage visible. A large part of our task is to understand what information you need and when you need it. Hence, I will ask you to talk aloud as you work. I will explain this in more detail and give you an opportunity to practice doing this shortly. Videotapes will be made of every scenario and computerized data is being collected as well.

In accordance with requirements of NUWC's Committee for the Protection of Human Subjects, strict procedures have been established to preserve the confidentiality of participants. Outside of the experimenters, no one can gain access to information that would reveal your identity. If you have any concerns that I should address, please ask them now.

⇒ **Hand them the Informed Consent forms and ask them to read and sign**

Talk-aloud training (5 - 10 min.)
The idea here is to give the subject's some specific instructions on what sorts of things we are going to want them to report and also to get them comfortable with talking aloud while working. To this end, the subject is given instructions ala Ericsson & Simon and a practice task to work on with tic-tac-toe. The subject plays a couple of games and is given feedback on the quality of the protocols
⇒ **Bring up the tic-tac-toe game and TTT video**

⇒ **Read:**

As you recall, I said that you are to talk aloud during this study. This may require some example and practice, so lets first watch the computer to it and then you'll play the computer.

⇒ **Play TTT for one approximately one minute.**

⇒ **Read:**

To reiterate, what I mean by talk aloud is that I want you to say out loud everything that you say to yourself silently. Just act as if you are alone in the room speaking to yourself. If you are silent for any length of time, I will remind you to keep talking aloud. Do you understand what I want you to do?

You may begin playing when you are ready

⇒ **If silent for more than 10-15 seconds say "keep talking"**

⇒ **Give feedback after each game**

⇒ **Continue until subject does not need to be reminded more than once during the entire game.**

⇒ **Quit HyperCard and MoviePlayer.**

⇒ **You should be at the 15-minute point.**

Introduction to Ned (25 - 30 min.)
<u>Freeplay Mode</u>

The goal of this part is to provide the subjects with enough knowledge about the interface to get good, clean data from the experiment sessions. Also, because data collection will

occur with information covered by the gray boxes, we can avoid extraneous mouse clicks by ensuring that subjects know where to find the information they are seeking.
Prompted Practice

⇒ **Bring up Ned and read:**

I will now show you the simulated combat control system (CCS). With it you can monitor all normal command functions, ship's control, Sonar, and TMA (MATE, Geo Sit, and plots). You can also order changes in own ship's speed, course, and depth. As this is a simulation designed for experimental purposes and unclassified, there are some limitations and unrealistic elements, which I will note as we go along.

I will introduce this simulation in two phases. First I will walk you through all of the displays and give you an opportunity to ask questions about the contents of the displays and to practice using the interface controls. I will then switch the simulation over to data collection mode, which is the mode in which you will be working for the main part of the study, to let you practice and explore the simulation under those conditions.

Please feel free to ask questions as we work through the displays, I want to make sure you understand how all of thee displays work before we start collecting actual data.

<u>I also want to remind you that this is an unclassified system being used for basic research.</u>

<u>This exercise will be audio/video recorded so please keep all remarks unclassified.</u>

⇒ **Make sure the Practice scenario is selected in the pop-up menu**

⇒ **Press the "Start" button**

⇒ **Let the subject have control of the computer**

⇒ **Ned will display the "Problem Description" and then "Status Report" windows. Read the text on these displays aloud and press the buttons to continue.**

⇒ **When it gets to OS control, read the following and point to each thing as you describe it.**

This window allows you to control own ship. These fields contain the <u>ordered</u> course, speed, and depth. To change course, select the field, type the new ordered course, select the direction of the turn, then click on this initiate change button. These fields above display the current actual, course speed and depth.

Go ahead and turn right to a bearing of 150, and slow down to 7 knots.

⇒ **While OS is maneuvering, read:**

Note that the fields up top change as OS changes, while the fields below remain constant.

⇒ **When maneuver is complete, read:**

This is the display navigation palette. You will be able to look only at one display at a time. To look at a display, simply press the appropriate button. We will first go to the broadband spherical waterfall display. Go ahead and click the button labeled "BB-Sphere".

⇒ **When BB-Sphere comes up, read:**

This is the waterfall window for the broadband sphere. It displays true bearing from 0 to 359 degrees and is divided into two parts. In the upper part the integration time is twenty seconds. In the lower part it is ten minutes. OS course is represented by this blue line in the upper part.

As you can see we have a trace here at a bearing of about 220, which corresponds to the merchant contact from our status report. To put a tracker on a target, just position the cursor over the track until it changes shape, then click. Go ahead and set a tracker on this target.

⇒ **When tracker is set, read:**

As you can see, the information on the track is displayed here. It assigns a sierra number, in this case sierra 1, and gives you the true bearing, SNR, and DE.

Along with a broadband sphere, you also have a broadband towed sonar sensor. If you don't have any questions about this display, go ahead and click the button labeled "BB-Towed".

⇒ **When BB-Towed comes up, read:**

Like the spherical sensor, the broadband towed display is also a waterfall display with 20 seconds of integration time in the top part and 10 minutes of integration time in the bottom part. Unlike the bb-sphere, this display plots conical angle from 0 to 180 degrees. You set a tracker in the same manner as in the other display - just move the cursor over the trace until it changes, and then click. Go ahead and set a tracker on this trace.

⇒ **When tracker is set, read:**

As before, the information on the track is displayed here. It assigns a sierra number, in this case sierra 1, and gives you the conical angle, both ambiguous bearings and SNR. In this field below, you can check the status of the towed array. As you can see, the array is currently stable.

The third sonar sensor available to you is narrowband towed. If you don't have any questions about this display, go ahead and click the button labeled "NB-Towed".

⇒ **When NB-Towed comes up, read:**

This display shows frequency on the horizontal axis and conical angle on the vertical axis. The frequencies displayed here are completely fabricated due to the unclassified nature of the simulation. The key point is that frequencies to the left are where you are likely to find a merchant contact and frequencies to the right are where you would find a submerged contact. As you can see, we have one of each currently on sonar. Go ahead and set trackers on both of these targets.

⇒ **When tracker is set, read:**

As you can see, the information on the tracks is displayed off to the right, and includes sierra number, conical angle, both ambiguous bearings and SNR. The status of the towed array is shown below.

Data from these three sensors are sent to several other displays, including a time bearing plot, time frequency plot, and TMA. Lets start with time bearing, go ahead and press the TimeBrng button on the palette.

⇒ **When TBR comes up, read:**

As you can see, this display plots 0 to 360 degrees of bearing over a 20 minute period. To use this display, first select the sensor for which you would like to see data. Go ahead and click the boxes labeled bb-spherical and nb-towed.

⇒ **When boxes are checked, read:**

The traces correspond in color to the label on the boxes, and the size of the boxes correspond to target. The larger boxes are Sierra 1 and the smaller ones are Sierra 2. To get the bearing rate, move the magnifying glass over the box of interest and read the bearing rate from the field below. Note that true bearing is also available. Each box represents 20 seconds of data, so the bearing and bearing rates you are reading have been averaged over 20 seconds.

The narrowband sensors send data to the time frequency plot, which we will look at next. If you don't have any questions, go ahead and press the TimeFreq button on the palette.

⇒ **When TFP comes up, read:**

This display plots a 40 hertz span of frequency over a 10 minute period. Each box represents data averaged over 6 seconds. This display works in a manner very similar to the time bearing window. First you select a target from the pop-up menu over here, then you move the magnifying glass over the box to read the frequency. The time that is displayed is the scenario time that the box was plotted.

If you have no questions about this display, we will move on to the target motion analysis window. Go ahead and click the TMA button.

⇒ **When TMA comes up, read:**

This display allows you to work one solution at a time for each target and sensor. You select the target/sensor from this pop-up menu. Go ahead and select the broadband spherical solution for sierra 1.

⇒ **When sierra1-bbs solution appears, read:**

As you can see, the system has provided you with a starting solution. This solution is displayed in the solution data box. It assigns the solution an ID#, and displays the range, bearing, course, speed, bearing rate, and range rate, as well as the age of the tracker sending data to TMA.

This solution is plotted on the geosit below. You have a choice of four zoom levels via this pop-up menu. The number on the menu corresponds to the outermost circle on the geosit. Go ahead and select the 40 kyd scale. The target is plotted as a circle with a course speed vector. A bearing line is plotted for the spherical array, and a parabola for the towed arrays.

Over to the left are plots of the solution bearing and the error stack. These can plot up to 15 minutes of data at a time.

To change the solution, press the tweak solution button. Go ahead and press it now.

⇒ **When tweak solution dialog appears, read:**

In this dialog, you can modify the solution range, bearing, course and speed. To change parameters, simply type the new values in the fields and press either the preview or the done button. The preview button will show the changes in the TMA window, but keep the tweak solution dialog open. The done button will make the changes and close the dialog. Go ahead and change a few parameters and then hit the preview button.

⇒ **When new solution displayed, read:**

As you can see, the new solution appears in all parts of the time window. If you choose to keep the solution, press the done button. If you want to modify it further, you can type new parameters in the fields and then hit preview or done. If you want to go back to the solution you had before you hit the tweak solution button, press cancel.

Note that whenever the tweak solution dialog is open, you will be unable to do anything else in the window, so be sure to close the dialog, either by hitting cancel or done, before attempting to do anything else. Go ahead and hit the done button now.

If there are no questions on the TMA window, lets move on to the Geosit window. Go ahead and click the GEOSIT button now.

⇒ **When GEOSIT comes up, read:**

This display will allow you to see solution plots on both targets simultaneously. To view a solution, simply select it from one of these two pop-up menus. The top, black menu is for sierra 1 and the lower, red menu is for sierra 2. As you can see, there is also a menu to select the scale of the plots, again, with the number on the menu corresponding to the outermost ring.

Go ahead and select the broad band spherical solution for sierra 1 and the narrowband towed solution for sierra 2.

⇒ **When solutions displayed, read:**

As you can see, each target is plotted as a circle with a course speed vector. The colors of the targets correspond to the colors on the pop-up menus, with sierra 1 in black and sierra 2 in red. Note that this display also plots bearing lines. It will plot a maximum of 5 bearing lines each 2 minutes apart.

If there are no questions on this display, let's move on to the line-of-sight display. Go ahead and hit the LOS button now.

⇒ **When LOS comes up, read:**

This is a passive display in that it has no data being sent to it. You will have to provide the values. In order to use it, enter values into each of these fields and then press the plot button. Go ahead and enter in some values now. Don't worry it they are correct or not for now.

⇒ **When LOS plotted, read:**

As you can see, the target's course is plotted above and ownship's is below.

If there are no questions about this display, let's move on to the final display, the sound velocity profile. Go ahead and hit the SVP button now.

⇒ **When LOS comes up, read:**

This display is inanimate and simply plots the current SVP. There are no actions that can be performed on this display.

Do you have any questions on this or any other display?

Okay, then we will move on to the next phase of the study where I show you some of the features of the simulation in its experiment mode. Go ahead and click the firing point procedures button to stop the simulation.

⇒ **Take control of the computer. When the main control window comes up click "Stop" then "Reset".**

<u>Experiment Mode</u>

The goal here is to familiarize the subject with the experiment-specific stuff - primarily using the gray boxes and talking aloud while working. It is important to describe in some detail the use of the boxes in the TBR and TFP, as they work a little differently than they do in other displays.

After the demonstration, the subject is instructed to try to determine a solution for the scenario and to talk aloud while doing so. Provide feedback on the quality of the protocols. When the subject is providing good quality protocols and is comfortable with the use of the gray boxes he is ready for the data collection phase.

⇒ **Select the "Run experiment" check-box and press the "Configure..." button.**

⇒ **Enter your initials, the subject number, and trial number of "0" in the Setup window**

⇒ **Press the "Create Data File..." button.**

⇒ **Make sure the "Collect Biographical Data" check box is <u>NOT</u> checked and the "Wash-up" one is. Press the "Done" button when finished.**

⇒ **Press the "Start" button to bring up the problem description window**

⇒ **Let the subject have control of the computer**

Prompted practice

⇒ **Read:**

Now we are going to look at experiment mode. There will be a few differences from what I just showed you. We are running the same practice problem that we did the last time so the problem description and scenario description are the same. Just go ahead and press the View Status report and Begin buttons on the first two windows.

⇒ **When OSC window comes up, read:**

One major difference is that all data fields are covered by gray boxes until you put the cursor in them and click the mouse button. These fields are exactly the same as the ones

you saw before, they are just covered up by the boxes. Go ahead and click on the box over ordered OS course.

⇒ **When OS course field is visible, read:**

When you move the mouse out of the field, the information is covered back up. Go ahead and move the mouse out of the field.

⇒ **When OS course field covered back up, read:**

Some of the boxes are very small, so try not to move the mouse out unintentionally.

The fields do receive data, but the values are not visible until you click on them. Likewise, you also won't be able to enter a value into a field unless it is visible. Generally speaking, you will be able to look at only one thing at a time.

Go ahead and turn to the right to 150 degrees, and then watch the values change in the course status field above.

⇒ **When OS has completed the maneuver, read:**

Okay, lets go to the narrowband towed display so you can practice setting a tracker in experiment mode.

⇒ **When NB-Towed comes up, read:**

You won't be able to set a tracker unless you uncover the waterfall display first. Go ahead and click on the waterfall box and set a tracker on the merchant.

⇒ **When tracker has been set, read:**

As you can see, the information on the tracker is also covered up. To see the conical angle, bearings, or SNR, you will have to click on the appropriate gray box. Go ahead and click on these.

The fields in the displays all work the same as this except for the Time Bearing and Time Frequency displays. Let's go to the time bearing display first.

⇒ **When TBR comes up, read:**

As before you will first have to select a sensor. Go ahead and click nb-towed.

⇒ **When narrowband-towed data plotted, read:**

You also have to choose whether you want to see bearing or bearing rate. You will only be able to see one at a time. Go ahead and click on the box next to bearing rate.

⇒ **When bearing rate box uncovered, read:**

Unlike the other gray boxes, this one will stay open when the mouse leaves. This is so you can move the magnifying glass around to get information from the data plotted on screen.

Go ahead and move the magnifier over some data.

⇒ **When subject has done this, read:**

This box will stay open until you select bearing. Go ahead and click on the box next to true bearing.

⇒ **When bearing box uncovered, read:**

As you can see, bearing rate is now covered, so you can only see the true bearing.

The TFP display works very much like this. Let's take a look at that one now.

⇒ **When TFP comes up, read:**

The frequency and time fields act in the same manner as bearing rate and true bearing fields in the TBR window. Go ahead and select S001 from the pop-up menu and then click the box next to freq.

⇒ **When subject has done this, read:**

Now when you move the magnifying glass over the data, you can read the frequency but not the time.

Free Practice

⇒ **Read:**

Now it is your turn to practice using the simulation in this mode. Feel free to ask questions as you work. I would also like you to practice talking aloud as you do this. When you are comfortable with the system and feel you have a reasonable solution on the targets, select this button labeled FPP. It stops the scenario and takes you to a display for a hot wash-up.

⇒ **Watch the subject interact with the system, answering any questions he has**

Wash-up Prompted Practice

⇒ **When the GEO DRAW window appears, read:**

Here we will want you to indicate what happened during the scenario. If there were discrepancies between your solution and the system, you should indicate **your solution** rather than the system solution.

Here is how it works. First you select a contact, in this case, Sierra 1A is already selected for you. So go ahead and click in on the geosit the bearing and range where you think the merchant was at the end of the leg.

⇒ **When the subject has dropped the target, read:**

The next mouse click draws a course-speed vector from the center of the target to wherever you click. Go ahead and do this now.

⇒ **When the subject has drawn the vector, read:**

A third mouse click draws a line indicating of range uncertainty surrounding the target. Click anywhere along the vector from the center of the geosit to the target.

⇒ **When the subject has drawn range uncertainty, read:**

As you can see, this draws a gray line surrounding the target.

You may indicate bearing ambiguity by selecting a second version of the same contact number, using, for example, 1A for the more likely ambiguous bearing and 1B for the other ambiguous bearing. Select sierra 1b from the pop up menu and draw the ambiguous bearing on the merchant, including a course speed vector and range uncertainty. Don't worry if it is correct or not, this is only practice.

⇒ **When the target has drawn sierra 1B on the geosit, read:**

If you want to delete a target, select the target from the pop-up menu and press the "Remove" button. Do this with sierra 1A. You will have to select it from the pop-up menu first.

⇒ **When Sierra1A has been deleted, read:**

Also indicate own ship course by selecting ownship from the menu and clicking to represent the appropriate course vector. Go ahead and draw ownship vector now.

⇒ **When OS vector has been drawn, read**

There are instructions on the window to remind you how to do all of this.

When you are satisfied, click the "Done" button. Go ahead and do this.

⇒ **When GEO TABLE window comes up, read**

You indicate your best guess for target course, speed, and range estimates on this page. You just type values into the appropriate fields.

I want you to provide information on both of these wash-up displays for each leg of the scenario, so if there is a leg you haven't provided information on yet, press this "Next Leg..." button. If have provided information on all of the legs of the scenario, press this "Done" button. This will end the exercise.

Wash-up Free Practice

At this point, I would like you to practice using both of these displays without me stepping you through it, so go ahead and press the next leg button and draw the last leg of the scenario.

⇒ **When the GEO DRAW window appears, read:**

Just go ahead and place the targets from the practice scenario on the geosit, making sure to include the course/speed vector and the range uncertainty. Also plot the course of OwnShip. Try using the "Remove" button to make sure you understand how it works. When you finish, press the "Done" button to get to the table screen. On the table screen, enter numerical values to represent what you drew on the graphical screen and hit the "Done" button when you are finished. If you have any questions while doing this, please ask.

⇒ **Watch the subject interact with the screens and answer any questions they have**

⇒ **When they press the "Done" button and get back to the main control screen, take control of the computer and press the "Stop", then the "Reset" button**

⇒ **You should be at the 45-minute point.**

Session 1 data collection (30 min.)
The subject is provided with the same cover story as the last time (i.e., Russia and Ukraine may be out to attack merchant shipping), and also given the specific status report for the first scenario - to include OS course, speed, depth, MERC bearing. The subject interacts with Ned, uninterrupted, until he feels confident enough in the solution to fire, or 30 minutes have passed. The experimenter plays a passive role, only prompting the subject to talk aloud when there is a > 10 second or so period of silence. Subjects will complete both the graphical and tabular forms of the hot wash-up

⇒ **Start the video tape recording**
⇒ **Read:**

If you have no further questions, we will start the first real scenario.

⇒ **Load the desired scenario by selecting it from the pop-up menu.**

⇒ **Make sure the "Run experiment" check-box is still checked and press the "Configure..." button.**

⇒ **Enter the appropriate values in the setup window, naming the data file according to the suggestion in the save file dialog. Make sure the "Collect Biographical Data" check box is NOT checked and the "Wash-up" one is. Press the "Done" button when finished.**

⇒ **Press the "Start" button to bring up the problem description window**

⇒ **Read:**

All scenarios take place with this same basic problem description that you saw in practice. We will begin with detection and run until the point at which you would like to initiate firing point procedures. You should indicate this by pressing the FPP button on the display navigation palette. You will then do the hot wash-up as you did in the practice scenario.

Please talk aloud during the entire problem - just say out loud everything that you say to yourself silently.

You may begin when ready.

⇒ **Watch passively as subjects complete scenario. Interrupt only if they are silent for 10-15 seconds or so, when you do so, just say "talk aloud".**

⇒ **When subject has completed the scenario, and gotten through the hot wash-up, take over the computer and press the "Stop", then "Reset" button.**

⇒ **See if the subject needs to take a short break**

⇒ **You should be at the 1:15 minute point.**

Session 2 data collection (30 min.)
Same as Session 1 except that subjects work a different scenario, and biographical data is collected
⇒ **Read:**

We will now start the next scenario.

⇒ **Load the desired scenario by selecting it from the pop-up menu.**

⇒ **Make sure the "Run experiment" check-box is still checked and press the "Configure..." button.**

⇒ **Enter the appropriate values in the setup window, naming the data file according to the suggestion in the save file dialog. Make sure the "Collect Biographical Data" AND "Wash-up" check boxes are both checked. Press the "Done" button when finished.**

⇒ **Press the "Start" button to bring up the problem description window**

⇒ **Read:**

Recall that all scenarios take place under the same basic conditions. As before, we will begin with detection and run until you decide you are ready to go to firing point procedures. After the hot wash-up, you will also be shown a screen containing some biographical questions.

Again, Please talk aloud during the entire problem

You may begin when ready.

⇒ **Watch passively as subjects complete scenario. Interrupt only if they are silent for 10-15 seconds or so, when you do so, just say "talk aloud".**

⇒ **When subject has completed the scenario, and gotten through the hot wash-up, and biographical data screens, take over the computer and press the "Stop", then "Reset" button.**

⇒ **See if the subject needs to take a short break**

⇒ **You should be at the 1:45 minute point.**

Experiment debrief and form-filling (15 - 25 min.)
The goal here is to examine recall of *both* scenarios and the distinctiveness of the recall. These should be done with paper and pencil and encourage the subjects to explain as they go. It might also be interesting to collect data on what the subjects made of the simulation (reality, usability, etc.) after they complete the recall session. This can be rather informal.
Scenario 1 Recall

⇒ **Load the practice scenario by selecting it from the pop-up menu.**

⇒ **Make sure the "Run experiment" check-box is still checked and press the "Configure..." button.**

⇒ **Enter the appropriate values in the setup window, entering 1W as the trial number for the first scenario**

⇒ **Name the data file according to the suggestion in the save file dialog. Make sure the "Collect Biographical Data" check box is not checked and the "Wash-up" one is. Press the "Done" button when finished.**

⇒ **Press the "Start" button to bring up the problem description window**

⇒ **Press the view status report and begin buttons as they come up, and then press the FPP button on the control window when it appears to get to the GEO DRAW window**

⇒ **Read:**

This is the last portion of the experiment. I would like you to use both the graphical and tabular wash-up screens to draw the events of both scenarios as you did before. Begin with the first scenario, drawing the targets on the graphical window and then entering numerical values in the tabular window. Be sure to do this for all targets and ownship and for each leg. You may begin when ready. When you are finished, hit the Done button on the tabular window.

⇒ **When subject has finished take over the computer and press "Stop", then the "Reset" button.**

Scenario 2 Recall

⇒ **Load the practice scenario by selecting it from the pop-up menu.**

⇒ **Make sure the "Run experiment" check-box is still checked and press the "Configure..." button.**

⇒ **Enter the appropriate values in the setup window, entering 2W as the trial number for the first scenario**

⇒ **Name the data file according to the suggestion in the save file dialog. Make sure the "Collect Biographical Data" check box is <u>NOT</u> checked and the "Wash-up" one is. Press the "Done" button when finished.**

⇒ **Press the "Start" button to bring up the problem description window**

⇒ **Press the view status report and begin buttons as they come up, and then press the FPP button on the control window when it appears to get to the GEO DRAW window**

⇒ **Read:**

I would now like you to recount the events in the second scenario. Be sure to do this for all targets and ownship and for each leg. You may begin when ready. When you are finished, hit the Done button on the tabular window.

⇒ **When subject has finished take over the computer and press "Stop", then the "Reset" button.**

Final Questions

⇒ **Transfer all files to zip disk and label appropriately**

⇒ **Hand the subject the additional questionnaire.**

⇒ **Stop Video Camera and Audio Recorder.**

Please take a minute to fill out the additional questionnaire.

INFORMED CONSENT

I have been informed about the purposes and procedures of this experiment according to enclosure (1) and am willing to participate under the conditions stated. I understand that:

(a) I may withdraw at any time with no penalty,
(b) All data will be confidential, and
(c) All data will be retained by the Principle Investigator named in enclosure (2).

Print Name: ____

Signature: ____

Date: ________________

GENERAL INFORMATION

This is an unclassified system being used for basic research. This exercise will be audio/video recorded. Please keep all remarks unclassified.

Today we will ask you to participate in two scenarios using a simplified simulation. First we will provide a high level overview of what you will be doing and why we are asking you to do it. When we finish we will tell you more specifically what we are studying and how your participation contributes to the goals of the study.

Purpose

The purpose of this experiment is to gather data on how command might use information that is typically available in the Combat Control System. As you know, the new SSN that is being planned will have a dedicated command workstation (CWS) to support the Approach Officer. As this is a new console, there is little known about how such a workstation will be used. This experiment is one in a series of studies to predict the answer to that question. One thing we do know, gleaned from the experience of many submarine officers, is that the CWS will require different displays than those currently available on operator consoles. Your participation will help determine the content of those displays.

Overview of the study

Your role will be that of the AO. Each scenario will begin with a status report on the current situation. Before the first scenario begins, you will be given practice with the experimental procedures and with the simulation.

Data collection in this experiment depends on making your information needs and usage visible. A large part of our task is to understand what information you need and when you need it. Hence, we request that you think aloud, saying whatever comes to mind, even if it might be irrelevant. You will be given an opportunity to practice doing this shortly. Videotapes will be made of every scenario and much computerized data is being collected as well. In accordance with requirements of NUWC's Committee for the Protection of Human Subjects, strict procedures have been established to preserve the confidentiality of participants. Outside of the experimenters, no one can gain access to information that would reveal your identity. If you have any concerns that we should address, please ask them now.

STUDY INFORMATION

Title of the Study:
Project NEMO

Principal Investigator (Name, Code, Phone):
Susan S. Kirschenbaum, Ph.D. Code 2211, 841-4381, x23835.

Sponsors:
Dr. S. Dickinson, NUWC IR Program Manager, and Dr. S. Chipman, Code 342, ONR.

The purpose of this work is to study and model the cognitive activity and behavior required for situation assessment. The nominal subject will be the submarine Approach Officer (AO). Situation assessment is a complex cognitive skill involving components (such as information search and assessment, memory, problem solving, and decision making) that have been studied in isolation, but never in the context of event-driven situation assessment. We expect our pursuit of situation assessment to result in advances in both theory and practice.

This experiment will take place in the NUWC Division Newport laboratory facility, the ARCH Laboratory at George Mason University, or at the participant's own facility. It will consist of subjects interacting with staged scenarios using a simplified simulation created for this experiment and hosted on a Macintosh. Subjects will be doing a task that is similar to their normal job including assessing data and giving orders for the control of the simulated submarine in a specified mission. They will each have two scenario segments. The total experimental time will be approximately two hours. All sessions will be video taped

This experiment is expected to require 10 to 15 subjects in each of three groups, novices (prior to first deployment), intermediates (after two to four years at sea), and experienced (Executive Officer or more experience). Subjects will be run individually, at the convenience of the subjects. No deception will be employed. The standard informed consent form will be used with a description of the experiment. Data recording will include computer interactions, videotapes of the screen, audio recordings of think-aloud protocols, and written questionnaires. All records will be retained by the P.I. No data will be identified by subject. Data will be analyzed by statistical and process-tracing methods, including cognitive modeling and other appropriate methods. Subjects will be able to request copies of resulting publications and will be given time at the end of sessions to ask questions.

The P.I. of this project is an experimental psychologist and agrees to conduct the experiment under conditions recommended by the American Psychological Association and approved by this committee.

APPENDIX C: EXPERIMENT KEY

SCEN	OS			MERC				ALFA				
	Course	Speed (knots)	Depth (ft)	Brng	Course	Speed (knots)	Range (yd)	Brng	Course	Speed (knots)	Range (yd)	Depth (ft)
Prac	000	9	400	270	090	9	5000					
c1	320	9	400	300	144	12	15000	020	200	7	7000	200
c2	233	9	400	153	354	15	15000	233	060	7	7000	200
z1	000	9	400	113	334	12	15000	043	184	10	7000	200
z2	225	9	400	160	160	12	15000	150	350	10	7000	200

Table C4.1. Initial Contact Geometry by Scenario.

Scenario	00:00-05:00					50:00-60:00
C1-60min	**00:00** MERC on sonar course 144 **05:00** ALFA on sonar course 200					**60:00** scenario ends
C2-60min	**00:00** MERC on sonar course 354 **05:00** ALFA on sonar course 060					**60:00** scenario ends
Z1-60min	**00:00** MERC on sonar course 334 **02:00** ALFA on sonar course 184	**05:30** ALFA course to 294	**09:00** ALFA course to 184	**12:00** ALFA course to 090		**60:00** scenario ends
Z2-60min	**00:00** MERC on sonar course 160 **02:00** ALFA on sonar course 350, speed 10	**07:00** ALFA course to 030, speed to 8	**09:30** ALFA course to 250, speed to 10			**60:00** scenario ends

Table C4.2. Timeline for 60 Minute Scenarios (course and speed remain the same as initial values above unless specified).

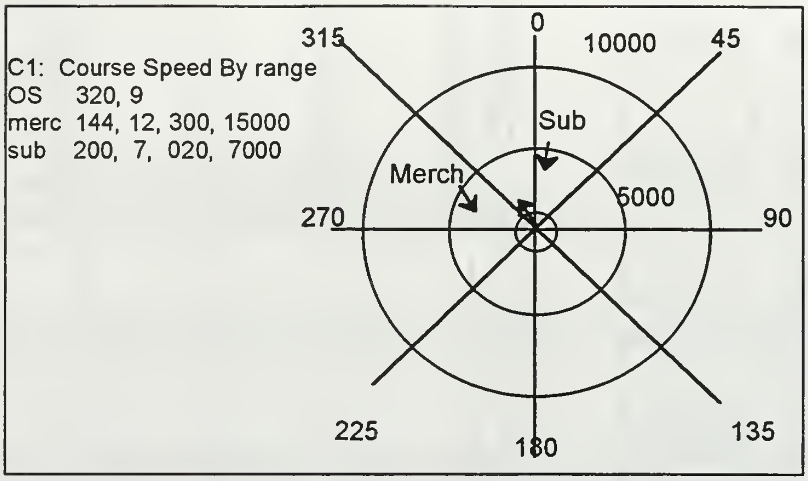

Figure C4.1. Scenario C1 Geometry.

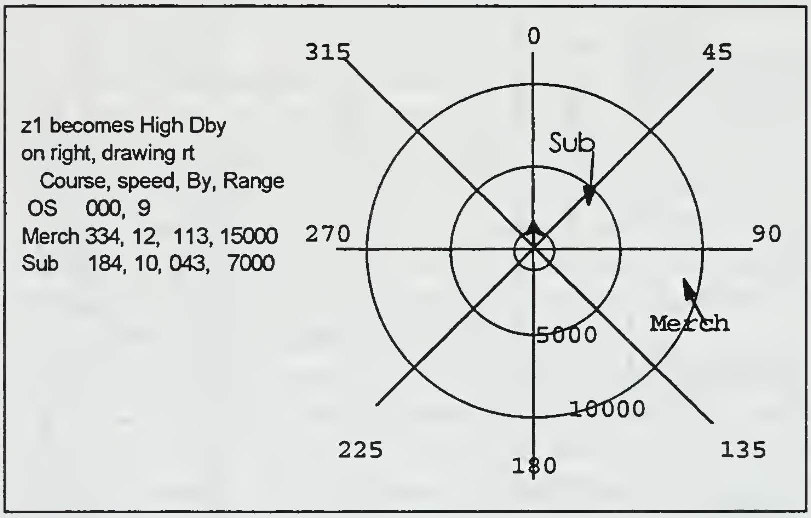

Figure C4.2. Scenario Z1 Geometry.

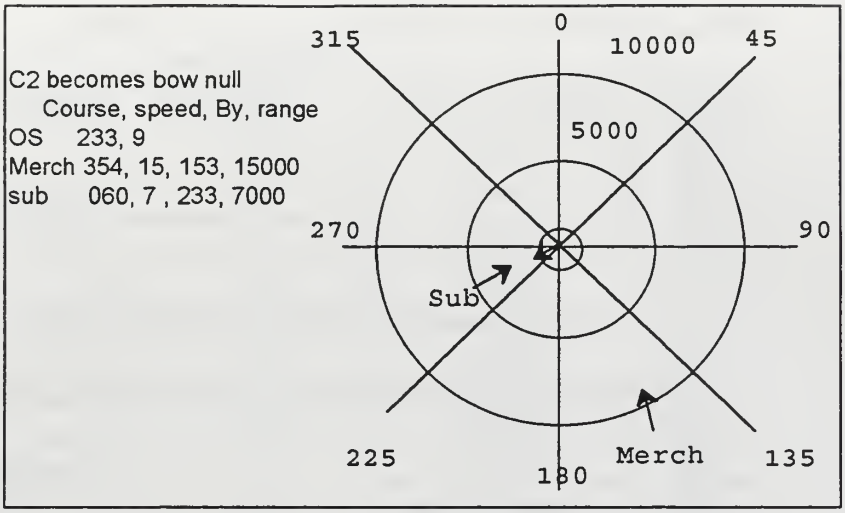

Figure C4.3 Scenario C2 Geometry.

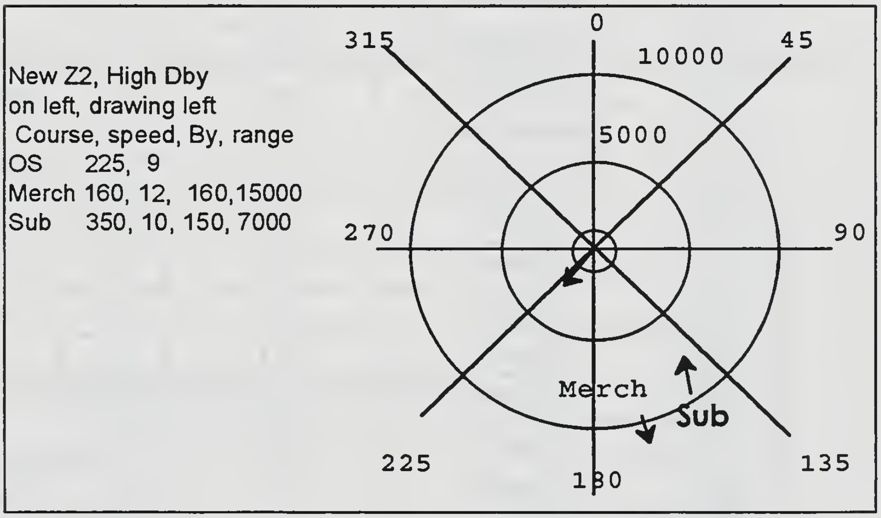

Figure C4.4 Scenario Z2 Geometry.

		Trial Order	
Subject	Experience level	Trial 1	Trial 2
S01	Novice	z2	c2
S02	Novice	z2	c1
S03	Novice	c2	z2
S04	Novice	z1	c1
S05	Novice	c1	z1
S06	Novice	c2	z1
S07	Novice	z1	c2
S08	Novice	c1	z2
S09	Intermediate	z2	c2
S10	Intermediate	z2	c1
S11	Intermediate	c2	z2
S12	Intermediate	z1	c1
S13	Intermediate	c1	z1
S14	Intermediate	c2	z1
S15	Intermediate	z1	c2
S16	Intermediate	c1	z2
S17	Expert	z2	c2
S18	Expert	z2	c1
S19	Expert	c2	z2
S20	Expert	z1	c1
S21	Expert	c1	z1
S22	Expert	c2	z1
S23	Expert	z1	c2
S24	Expert	c1	z2

Table C4.3 Latin Square Design.

APPENDIX D: ADDITIONAL QUESTIONAIRRE

ADDITIONAL QUESTIONNAIRE

DATE:______________________
INTERVIEWER:_______________
SUBJECT:__________________

1. Could you tell me what you thought of the situation?

2. Was the situation "realistic" enough for you? Any comments?

1 Very Unrealistic
2 Unrealistic
3 Borderline
4 Realistic
5 Very Realistic

3. How difficult were the scenarios? (Please provide a score for each run) Any comments?

1 Very Difficult
2 Difficult
3 Borderline
4 Easy
5 Very Easy

4. Please rate the effectiveness of each display.

1 Very Ineffective
2 Ineffective
3 Borderline
4 Effective
5 Very Effective

LOS_____________OSC_____________SVP_____________
TMA_____________TAPBB___________TAPNB___________SAPBB___________
TF______________TB______________GEOSIT__________

5. Please rank the usefulness of the displays. One for the most useful, 10 for the least. No ties allowed.

LOS_____________OSC_____________SVP_____________
TMA_____________TAPBB___________TAPNB___________SAPBB___________
TF______________TB______________GEOSIT__________

6. The ultimate goal of the project is to provide for the design of the CWS of the NSSN. If you were in charge, what kind of design would you make? Include any and all displays/information/graphical interfaces that you desire.

(Use Blank sheets provided)

7. Any more comments?

APPENDIX E: ASSUMED TORPEDO CHARACTERISTICS

Name:	MK-48 Heavyweight Torpedo	
Manufacturer:	Gould Electronics	
Diameter:	21	inch
Length:	230	inch
Weight	3480	pounds
Range:	35000	yards
Speed:	55	knots
Operating Depth:	2500	feet
Acoustic acquire range:	2000	yards

(Friedman, 1983)

APPENDIX F: VB MARCO CODE

```
Option Base 1

Sub doall()
Call breakoutdata
Call displayanalysis
End Sub
Sub breakoutdata()
Dim newdata, newtruth, datcount, truthcount
datcount = 0
truthcount = 0
Set newdata = ActiveWorkbook.Worksheets.Add
Set newtruth = ActiveWorkbook.Worksheets.Add
newdata.Name = "Data"
newtruth.Name = "Truth"
For Each rw In Sheets(3).Rows
  If rw.Cells(1) = "" And rw.Row > 1 Then
    Exit For
  Else
     If rw.Cells(1) = ("TRU") Then
             truthcount = truthcount + 1
             newtruth.Rows(truthcount).Value = rw.Value
      ElseIf rw.Row > 6 Then
             datcount = datcount + 1
             newdata.Rows(datcount).Value = rw.Value
      End If
    End If
Next rw
Call cleantruth(newtruth)
Call cleandata(newdata)
End Sub

Sub cleantruth(truthsheet)
For N = 1 To 5
    truthsheet.Columns(1).Delete
Next N
truthsheet.Columns(2).Delete
truthsheet.Columns(1).NumberFormat = "h:mm:ss"
End Sub

Sub cleandata(datasheet)
For N = 8 To 20
    datasheet.Columns(8).Delete
Next N
With datasheet
     .Columns(6).NumberFormat = "h:mm:ss"
     .Rows(1).Font.Bold = True
     .Columns("A:BW").AutoFit
     .Range("A:BW").Sort keyl:=.Columns("E"), header:=xlYes
End With
datasheet.Activate
ActiveWindow.SplitRow = 1
ActiveWindow.FreezePanes = True
End Sub
```

```
' Master function to run the analysis by display
Sub displayanalysis()
    Call displayaccesssummary
    Call displaysequence
    Call addfreqchart
    Call addtotchart
    Call addavgchart
    Call repositioncharts
End Sub

Sub displayaccesssummary()
    Dim countsheet As Variant
    Dim discount, rowcount, oldtime, newtime As Integer
    Dim fpctstr, tpctstr As String      'sumstr, avgstr, stdevstr,
    Dim labarray, disarray, timearray() As Double
    disarray = Array("GEOSIT", "LOS", "OSC", "SONAR-BB-SPHERE",
      "SONAR-BB-TOWED", "SONAR-NB-TOWED", "SVP", "TBR", "TFP", "TMA")
    labarray = Array("Display", "Frequency", "% Frequency", "Tot Time",
      "%Time", "Avg Time", "Std Dev")
    rowcount = 1
    Set countsheet = ActiveWorkbook.Worksheets.Add
    Call prepcountsheet(countsheet, labarray)
 For Each d In disarray
    discount = 0
    oldtime = 0
    ReDim timearray(1)
    For Each rw In Worksheets("Data").Rows
        If rw.Cells(1) = "" Then
            rowcount = rowcount + 1
            'sumstr = "=sum(R" & rowcount & "C8" & ":R" & rowcount &
            "C" & UBound(timearray) + 6 & ")"
            'avgstr = "=average(R" & rowcount & "C8" & ":R" & rowcount
            & "C" & UBound(timearray) + 6 & ")"
            'stdevstr = "=stdev(R" & rowcount & "C8" & ":R" & rowcount
            & "C" & UBound(timearray) + 6 & ")"
            fpctstr = "=(R" & rowcount & "C2" & "/" & "R12C2)"
            tpctstr = "=(R" & rowcount & "C4" & "/" & "R12C4)"
            With countsheet
                .Range(.Cells(rowcount, 8), .Cells(rowcount, discount +
                  7)).FormulaArray = timearray.Cells(rowcount, 1).Value
                  = d.Cells(rowcount, 2).Value = discount
                  .Cells(rowcount, 3).FormulaR1C1 = fpctstr
'                 .Cells(rowcount, 4).FormulaR1C1 = sumstr
                  .Cells(rowcount, 5).FormulaR1C1 = tpctstr
 '                .Cells(rowcount, 6).FormulaR1C1 = avgstr
 '                .Cells(rowcount, 7).FormulaR1C1 = stdevstr
                  .Cells(rowcount, 4).Value = mysum(timearray)
                  .Cells(rowcount, 6).Value = myaverage(timearray)
                  .Cells(rowcount, 7).Value = mystdev(timearray)
            End With
            Exit For
        ElseIf rw.Cells(2) = "DISPLAY-CHANGE" And rw.Cells(3) = d Then
                discount = discount + 1
                newtime = rw.Cells(5).Value
                 ReDim Preserve timearray(UBound(timearray) + 1)
                 timearray(discount) = newtime - oldtime
                 oldtime = newtime
```

```
        ElseIf rw.Cells(2) = "DISPLAY-CHANGE" Then
            oldtime = rw.Cells(5).Value
        End If
    Next rw
Next d
End Sub
Sub prepcountsheet(sheet, labelarray)
    With sheet
        .Name = "Displays"
        .Range("A1:G1").FormulaArray = labelarray
        .Range("A1:G1").Font.Bold = True
        .Cells(12, 1).Value = "Totals"
        .Cells(12, 1).Font.Bold = True
        .Cells(12, 2).FormulaR1C1 = "=sum(R2C2:R11C2)"
        .Cells(12, 4).FormulaR1C1 = "=sum(R2C4:R11C4)"
        .Range("A1:G11").Borders.LineStyle = xlContinuous
    End With
End Sub
Function mysum(anarray)
    For Each el In anarray
        mysum = mysum + el
    Next el
End Function

Function myaverage(anarray)
    If UBound(anarray) > 1 Then
     myaverage = mysum(anarray) / (UBound(anarray) - 1)
    Else
     myaverage = 0
    End If
End Function

Function mystdev(anarray)
    Dim sm, sqrd, N As Integer
    N = UBound(anarray) - 1
    For Each el In anarray
        sm = sm + el
        sqrd = sqrd + el ^ 2
    Next el
    If N > 1 Then
     mystdev = Sqr(((N * sqrd) - sm ^ 2) / (N * (N - 1)))
    Else: mystdev = 0
    End If
End Function

Sub displaysequence()
Dim labarray, disarray, rowcount, oldtime, newtime
disarray = Array("GEOSIT", "LOS", "OSC", "SONAR-BB-SPHERE",
"SONAR-BB-TOWED", "SONAR-NB-TOWED", "SVP", "TBR", "TFP", "TMA")
labarray = Array("Time", "Display", "Duration")
rowcount = 16
For Each d In disarray
    oldtime = 0
    For Each rw In Worksheets("Data").Rows
        If rw.Cells(1) = "" Then
            Exit For
        ElseIf rw.Cells(2) = "DISPLAY-CHANGE" And rw.Cells(3) = d Then
```

```
                newtime = rw.Cells(5).Value
                rowcount = rowcount + 1
            With Worksheets("DIsplays")
                .Cells(rowcount, 1).Value = newtime
                .Cells(rowcount, 2).Value = d
                .Cells(rowcount, 3).Value = newtime - oldtime
            End With
                oldtime = newtime
        ElseIf rw.Cells(2) = "DISPLAY-CHANGE" Then
            oldtime = rw.Cells(5).Value
        End If
    Next rw
Next d
With Worksheets("Displays")
    .Range("A15:C15").FormulaArray = labarray
    .Range("A15:C15").Font.Bold = True
    .Range("A16:C1000").Sort key1:=.Columns("A")
    .Columns("A:BW").AutoFit
End With
End Sub

Sub addfreqchart()
    Charts.Add
    ActiveChart.ChartType = xlColumnClustered
    ActiveChart.SetSourceData
    Source:=Sheets("Displays").Range("A1:A11,C1:C11"), _
        PlotBy:=xlColumns
    ActiveChart.Location Where:=xlLocationAsObject, Name:="Displays"
    With ActiveChart
        .HasTitle = True
        .ChartTitle.Characters.Text = "Display Frequency"
        .Axes(xlCategory, xlPrimary).HasTitle = False
        .Axes(xlValue, xlPrimary).HasTitle = True
        .Axes(xlValue, xlPrimary).AxisTitle.Characters.Text = "%
      Frequency".HasLegend = False
    End With
End Sub

Sub addtotchart()
    Charts.Add
    ActiveChart.ChartType = xlColumnClustered
    ActiveChart.SetSourceData
Source:=Sheets("Displays").Range("A1:A11,E1:E11"), _
        PlotBy:=xlColumns
    ActiveChart.Location Where:=xlLocationAsObject, Name:="Displays"
    With ActiveChart
        .HasTitle = True
        .ChartTitle.Characters.Text = "Display Time"
        .Axes(xlCategory, xlPrimary).HasTitle = False
        .Axes(xlValue, xlPrimary).HasTitle = True
        .Axes(xlValue, xlPrimary).AxisTitle.Characters.Text = "% Time"
        .HasLegend = False
    End With
End Sub
```

```
Sub addavgchart()
    Charts.Add
    ActiveChart.ChartType = xlColumnClustered
    ActiveChart.SetSourceData
Source:=Sheets("Displays").Range("A1:A11,F1:F11"), _
        PlotBy:=xlColumns
    ActiveChart.Location Where:=xlLocationAsObject, Name:="Displays"
    With ActiveChart
        .HasTitle = True
        .ChartTitle.Characters.Text = "Average Display TIme"
        .Axes(xlCategory, xlPrimary).HasTitle = False
        .Axes(xlValue, xlPrimary).HasTitle = True
        .Axes(xlValue, xlPrimary).AxisTitle.Characters.Text = "TIme
(secs)".HasLegend = False
    End With
End Sub

Sub repositioncharts()
    ActiveSheet.Shapes("Chart 3").IncrementLeft 496#
    ActiveSheet.Shapes("Chart 3").IncrementTop -8#
    ActiveSheet.Shapes("Chart 2").IncrementLeft 81#
    ActiveSheet.Shapes("Chart 2").IncrementTop 387#
    ActiveSheet.Shapes("Chart 1").IncrementLeft 69#
    ActiveSheet.Shapes("Chart 1").IncrementTop -8#
End Sub
```

APPENDIX G: OPTIMIZATION FORMULATION AND CODE

A. NPS FORMULATION

For each trial i, GAMS is used to determine the closest point of intersection of the submarine and torpedo trajectories, if the intersection occurs before TMAX. Otherwise, it determines the range at TMAX.

Problem: For the CPA parameters (Time, Range) for the weapon and the target.

INDEX: i TRIAL i=1..I

Data:	Xso_i	initial submarine x position for trial i
	Yso_i	initial submarine y position for trial i
	Xto	initial torpedo x position for trial i
	Yto	initial torpedo y position for trial i
	Vsx_i	submarine velocity in the x direction for trial i
	Vsy_i	submarine velocity in the y direction for trial i
	Vtx_i	torpedo velocity in the x direction for trial i
	Vty_i	torpedo velocity in the y direction for trial i
	Tmax	maximum run time of torpedo in seconds
Variables:	Rh_i	CPA range for trial i
	T_i	CPA time for trial i

Formulation for trial i:

min Rh_i

s.t Rh_i=sqrt(((Xso+Vsx*T_i)-(Xto+Vtx*T_i))^2+ ((Yso+Vsy* T_i)-(Yto+Vty* T_i))^2)

0<=T_i<+Tmax

Output: Rh_i

T_i

B. GAMS CODE

```
* DAVID SOLDOW
* CPA OPTIMIZATION ROUTINE
$Title:     CPA optimization routine
SETS
I /1*65/
PARAMETERS
Xso(I) /1 2881.801,(EDITED FOR SPACE) 65  2116.524/
Yso(I) /1 -4971.37,(EDITED FOR SPACE) 65  437.9259/
Vsx(I) /1 -5.16831,(EDITED FOR SPACE) 65  -1.31678/
Vsy(I) /1 -1.88111,(EDITED FOR SPACE) 65  -3.61782/
Vtx(I) /1 11.33185,(EDITED FOR SPACE) 65  29.35145/
Vty(I) /1 -28.0473,(EDITED FOR SPACE) 65  7.318137/;
SCALAR  TMAX /1145.5/;
SCALAR  Xto /0/;
```

```
SCALAR  Xto /0/;
SCALAR  Yto /0/;
Scalars
Xsoi, Vsxi, Vtxi, Ysoi, Vsyi, Vtyi ;
VARIABLES
      Z      CPA RANGE FOR TRIAL I
      T      CPA TIME FOR TRIAL I ;
T.LO=0;
T.UP=TMAX;
EQUATIONS
CPA     OBJECTIVE VALUE FOR TRIAL i;
CPA  .. Z=e=SQRT(sqr((XsoI+VsxI*T)-(Xto+VtxI*T))
            +sqr((YsoI+VsyI*T)-(Yto+VtyI*T)));
MODEL SHOTCPA /ALL/;
FILE REPORT/SHOTCPA.RPT/;
PUT REPORT; REPORT.ND=5;
PUT /'TRIAL     RH(I)   T(I)';
PUT /'----------------------';
LOOP(I,
  Xsoi=xso(i);
  Vsxi=vsx(i);
  Vtxi=Vtx(i);
  Ysoi=Yso(i);
  Vsyi=vsy(i);
  Vtyi=vty(i);
  SOLVE SHOTCPA USING NLP MINIMIZING Z;
  PUT I.tl;
  PUT Z.l;
  PUT T.l;
);
PUTCLOSE REPORT;
```

C. OUTPUT

```
TRIAL        RH(I)        T(I)
----------------------------
1            214.395      186
2            214.5673     124
(EDITED FOR SPACE)
65           298.5145     66
```

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